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ECONOMIC GEOLOGY

BY

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PREFACE

THE following work on the Economic Geology of the United States covers essentially the ground which is gone over in the elementary course in this subject in Cornell University, but it is hoped that it will prove useful as a text-book in other colleges.

The mode of arrangement is markedly different from that found in other books on the same subject, in that the non-metallic materials are discussed first and the ore deposits last. This, to the author, seems the most desirable method of treatment, for the reason that the non-metallics are not only the most important, the value of their production having exceeded the metallics by over one hundred and fifty million dollars in 1903, but also because it leads from a discussion of the simpler to the more complex forms of mineral deposits.

It has not been thought desirable to include a chapter on geologic and physiographic principles, since the space which could be allotted to it is altogether too small, and, moreover, the study of economic geology presupposes a knowledge of geology and mineralogy on the part of the student. While the references given at the end of each chapter do not include every paper that has been written on the subject to which they refer, still it is believed that they are sufficiently numerous to permit one to follow out the subject in considerable detail if he so desire.

In the preparation of the manuscript all available sources of information have been freely drawn upon, and the numbers in parentheses in the text refer to the numbered references at the end of each chapter.

All statistical figures, unless otherwise stated, are taken from the reports of the United States Geological Survey.

Descriptions of mineral occurrences in foreign countries are not included, except in a few cases where the deposits serve as an important if not the only source of supply for the United States.

The writer wishes to express his thanks to Professor R. S. Tarr for examination and criticism of much of the manuscript, and to W. E. McCourt, Instructor in Geology, and H. Leighton, Assistant in Geology, for aid in the preparation of drawings and statistical tables. For the loan of photographs or cuts acknowledgments are due to Messrs. H. F. Bain, J. E. Spurr, J. M. Boutwell, G. H. Eldridge, W. Lindgren, F. H. Oliphant, and J. H. Pratt of the United States Geological Survey; Professor A. C. Lane, Michigan Geological Survey; Dr D. H. Newland, New York State Museum; Professor C. C. O'Harra, South Dakota School of Mines; Professor E. A. Smith, Alabama Geological Survey; Professor G. H. Perkins, Vermont Geological Survey; Dr. H. B. Kümmel, New Jersey Geological Survey; Dr. W. B. Phillips, Texas Geological Survey; Dr. G. P. Merrill, United States National Museum; also to Messrs. H. W. Turner, F. S. Witherbee, A. W. Sheafer, L. Martin, Wiley & Sons, Vermont Marble Co., and Bedford Quarries Co.

CORNELL UNIVERSITY,
ITHACA, N.Y., June, 1905.

PREFACE TO THE SECOND EDITION

THE publication of a second edition has become necessary in such a comparatively short time, that it has not been deemed advisable to materially alter the text. An attempt has, however, been made to correct all errors of which the author has knowledge. Recognizing the value of fresh statistics, those for 1905 (the most recent available), have been given in an appendix, and for the benefit of those who make use of the bibliography, a second appendix has been included, containing a list of the more important papers published since the appearance of the first edition.

CORNELL UNIVERSITY,
ITHACA, N.Y., Nov. 10, 1906.

PREFACE TO THE THIRD EDITION

ALTHOUGH it is but little more than four years since the first edition of this work appeared, our knowledge of the subject of economic geology has expanded to such an extent, and so many papers of importance have been published, that it was deemed advisable to make a somewhat complete revision of the book.

In doing this the author has been guided partly by the dictates of his own experience as a teacher of economic geology, and in part by the suggestions of other teachers who have found the work useful; to these persons the writer expresses his grateful acknowledgments.

While considerable matter of a general character dealing with the principles of the subject has been added, a number of additional descriptions of individual occurrences have also been included, without abandoning the plan of giving the more important ones in coarser type.

As in earlier editions, the statistics given are in all cases taken from the *Mineral Resources* issued by the United States Geological Survey, except some for 1909, which are from the *Engineering and Mining Journal.*

In the compilation of a mass of data from many scattered sources, such as has been involved in the preparation of this book, every reasonable attempt has been made to guard against errors, but it is perhaps too much to hope that none have crept in.

The author takes pleasure in here acknowledging the efficient and tireless aid which has been rendered him in the preparation of this edition by Mr. C. A. Stewart, Instructor in Economic Geology, Cornell University. Thanks are also due for the loan of photographs or cuts to: Mr. Donald Steel, Cornell University; Mr. F. L. Ransome, United States Geological Survey; Professor J. P. Rowe, Missoula, Mont.; Messrs. D. H. Newland and H. Leighton, New York Geological Survey; Professor S. W. McCallie, Georgia Geological Survey; Dr. H. B. Kümmel, New Jersey Geological Survey; The Barber Asphalt Company, Philadelphia, Pa.; and the Pike Manufacturing Company, Pike Station, N.H.

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PART I

NON-METALLIC MINERALS

CHAPTER I

COAL

Kinds of Coal. — There is such an intimate gradation between vegetable accumulation now in process of formation and mineral coal that it is generally admitted that coal is of vegetable origin. By a series of slow changes (p. 11) the vegetable remains lose water and gases, the carbon becomes concentrated, and the materials assume the appearance of coal. To the several stages of this process the following names are given: peat, lignite, subbituminous, bituminous, semi-bituminous, semi-anthracite, and anthracite.

Peat (119–130.) — This, which represents the first stage in coal formation, is formed by the growth and decay of grasses, sphagnum, and other plants in moist places. A section in a peat bog from the top downward may show: (1) A layer of living plants; (2) a layer of dead plant fibers, whose structure is clearly recognizable and which grades into (3) a layer of fully formed peat, a dense, brownish black mass, of more or less jellylike character, in which the vegetable structure is often indistinct.

The following analyses show the difference in composition of the different layers.[1] They also show that while during this change the hydrogen and oxygen diminish, the carbon increases in proportion.

ANALYSES OF DIFFERENT LAYERS OF A PEAT BOG

MATERIAL	CARBON	HYDROGEN	OXYGEN	NITROGEN
Sphagnum	49.88	6.54	42.42	1.16
Porous, light brown sphagnum peat	50.86	5.8	42.57	.77
Porous, red-brown peat	53.51	5.9	40.59	
Heavy brown peat	56.43	5.32	38.25	
Heavy black peat	59.7	5.7	33.04	1.56

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[1] The fact that sphagnum occurs on the surface is not necessarily an indication that it was the only peat-forming plant present.

Lignite. — This substance, also called *brown coal*, representing the second stage in coal formation, is usually brown in color, woody in texture, and has a brown streak. It burns readily, but with a long smoky flame, and with lower heating power than the higher grades of coal. Because of the large amount of moisture it often dries out on exposure to the air, and rapidly disintegrates to a powdery mass.

The lignites have been found in the more recent geological periods. Because of the greater age and the greater compression of vegetable matter, due to the pressure of overlying strata, lignite resembles true coal more closely than peat. In fact, in favorable situations, the alteration of Tertiary and Cretaceous coals has proceeded as far as to transform them beyond the stage of lignite.

Jet is a coal-black variety of lignite, with resinous luster and sufficient density to permit its being carved into small ornaments. It is obtained on the Yorkshire coast of England, where a single seam produced 5180 pounds, valued at $1250. According to Phillips, jet is simply a coniferous wood, still showing the characteristic structure under the microscope. ("Geology of England and Wales," p. 278.)

Sub-bituminous Coal or Black Lignite. — A grade intermediate between lignite and bituminous, and sometimes difficultly distinguishable from these. It is often black, and of brilliant luster. Campbell (13) has pointed out that it checks irregularly on drying and when weathered splits parallel with the bedding, while bituminous coal shows a columnar cleavage.

Bituminous Coal. — This represents the fourth stage in coal formation. It is denser than the lignites, deep black, comparatively brittle, and breaks with cubical or sometimes conchoidal fracture. On superficial inspection it usually shows no trace of vegetable remains; but in thin sections examined under the microscope, traces of woody fiber, lycopod spores, etc., are commonly seen. Bituminous coal burns readily, with a smoky flame of yellow color, but with greater heating power than lignite. It does not disintegrate on exposure to air as readily as lignite does. Most bituminous coal is of earlier age than lignite; but where the two occur in the same formation, as in parts of the West, the lignite is commonly in horizontal strata, while the bituminous coal occurs in areas of at least slight disturbance.

When freed of their volatile hydrocarbons and other gaseous constituents by heating to redness in a coke oven, many bituminous coals cake to a hard mass called *coke*. Since all bituminous coals do not possess this characteristic, it is customary to divide these coals into *coking* and *non-coking* coals.

The cause of coking is not clearly understood, and the chemical analysis does not appear to throw much light on the matter. It has been suggested [1] that the quality of coking may be due to the presence of gelosic algal, or sapropelic matter, in the original ingredients of the fuel. A determination of the coking qualities of a coal has usually involved a practical test, but it now appears that the coking qualities of a coal can be inferred with fair accuracy by its behavior when ground in an agate mortar. Coals of good coking character stick to the mortar, while those of opposite quality are easily brushed loose (28).

The coking value of a coal (20) seems to be indicated with fair accuracy by the hydrogen-oxygen ratio, calculated on a moisture-free basis. Practically all coals with $\frac{H}{O} > 58$ per cent seem to possess coking qualities. Most coals with $\frac{H}{O}$ down to 55 make coke of some kind, and a few with ratios as low as 50 will coke, though the product is rarely good.

The hydrogen-oxygen ratio may fail as a guide in those coals undergoing anthracitization.

The formation of coke by natural processes is referred to on p. 4.

Cannel Coal. — This is a compact variety of non-coking bituminous coal, with a dull luster and conchoidal fracture. Owing to its unusually high percentage of volatile hydrocarbons, upon which its chief value depends, cannel coal ignites easily, burning with a yellow flame, and when heated tends to decrepitate.

Semi-bituminous Coal. — This term was proposed by H. D. Rogers as early as 1858 [2] to apply to those grades above bituminous, whose volatile matters were between 12 and 18 per cent; while Frazer, in 1879,[3] used it to include those coals whose "fuel-ratios" (p. 13) ranged from 8 to 5.

Semi-anthracite Coal. — This term was employed by Rogers at the same time, and included those coals between bituminous and anthracite having less than 10 per cent volatile matter. Frazer later included under it those coals whose fuel-ratios ranged from 12 to 8.

Both terms persist, perhaps unfortunately, to the present day, and are sometimes no doubt rather loosely used. Possibly the disagreement among different people as to what shall be included under these terms may be partly responsible for the confusion.

Anthracite Coal. — This coal is black, hard, and brittle, with high luster and conchoidal fracture. It represents the last stage in the formation of coal, and shows no traces of vegetable structure within its mass, although plant impressions are often abundant in the rocks immediately above and below it. Anthracite has a lower percentage of volatile hydrocarbons and higher percentage of fixed carbons than any of the other varieties. On this account, it ignites much less easily and burns with a short flame, but gives great heat.

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[1] White, D., Science, N.S., XXVII: 538. [2] Geology of Pennsylvania, II: 983.

[3] Second Pennsylvania Geological Survey, Rept. MM: 148, 1879.

The geological distribution of anthracite is more restricted than that of bituminous coal, and in fact its occurrence is often more or less intimately connected with dynamic disturbances.

Carbonite or Natural Coke. — This term is applied to natural coke, which is formed by igneous rocks cutting across bituminous coal seams. As illustrative may be mentioned an occurrence in central Utah,[1] where " dikes of igneous rocks ten feet in width have cut vertically across the coal bed, nine to sixteen feet thick, metamorphosing the coal into a coke-like substance to a distance of three feet on either side. The coal thus fused is distinctly columnar, the columns standing perpendicular to the face of the dike; it has a graphitic luster, but is not vesicular like artificial coke." Natural coke is also found in New Mexico, Colorado, and Virginia.

The higher quantity of volatile matter in carbonite than artificial coke may be due to its having formed at some depth below the surface, thus preventing the escape of the volatile matter, short heating, or enrichment by gases from the neighboring coal.

ANALYSES OF NATURAL COKE

	I	II	III
Moisture	1.116	.32	4.55
Volatile hydrocarbons	11.977	20.38	4.43
Fixed carbon	75.081	65.90	84.67
Ash	11.826	13.10	6.35

I. Richmond, Va., coal basin. — Watson, Min. Res. of Va., p. 343, 1907. II. Book Cliffs coal field, Utah. — Taff, Science, N.S. XXIII : 696, 1906. III. Cerrillos Hills district, N.M. — Johnson, Sch. of M. Quart., XXIV: 492, 1903.

Proximate Analysis of Coal. — An elementary analysis of coal (see p. 12) is of comparatively little practical value. Therefore proximate analyses are commonly employed, in which the probable method of combination of the elements is given. By the proximate method the elements in the coal are grouped as moisture, volatile hydrocarbons, fixed carbon, ash, and sulphur.[2]

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[1] Taff, J. A., Science, N.S., XXIII : 696, 1906.

[2] The proximate analysis, though apparently a simple operation, needs to be carefully carried out to prevent variable results. See in this connection U. S. Geol. Surv., Prof. Pap. 48, I.

The moisture can be driven off at 100° C. and is usually highest in peat and lignite; the volatile hydrocarbons are the easily combustible elements, and decrease toward the anthracite end of the series; the fixed carbon burns with difficulty and is highest in the anthracite coals. The ash represents noncombustible mineral matter and bears no direct relation to the kind of coal; and the same is true of sulphur, which is present as an ingredient of pyrite or gypsum.

The value of coal for fuel or other purposes is determined mainly by the relative amounts of its fuel constituents, viz., the volatile hydrocarbons and the nonvolatile or fixed carbons. The fuel value, or *fuel ratio*, is determined by dividing the fixed carbon percentage by that of the volatile hydrocarbons.

The fixed carbon represents the heating element of the coal, while the volatile hydrocarbons burn easily, but have little heating power. The heating power and fuel ratio will, therefore, increase together. This increase in the heating power of the coal is only true, however, up to a certain point, after which the difficulty in making the coal burn offsets the extra amount of heat developed. Coals with a high percentage of fixed carbon develop great heating power, while those lower in fixed carbon and high in volatile hydrocarbons lack in heating power, but are free burning.

Moisture is a nonessential constituent of coal. It not only displaces so much combustible matter, but requires heat for its evaporation. When present in large amounts it often causes the coal to disintegrate while drying out. It ranges from perhaps 1 per cent in anthracite to 20 or 30 per cent in lignites.

Ash also displaces combustible matter, but otherwise it is in most cases an inert impurity. The clinkering of coal is commonly due to a high percentage of fusible impurities in the ash, and for metallurgical work the composition of the ash often has to be considered.

The following analyses will also serve to illustrate the composition of the ash:—

ASH ANALYSES

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO_2	SO_3	Na_2O, K_2O	Cl	P_2O_5
Peat, average of several . . .	25.50	5.78	18.70	24.00	3.20	—	7.50	1.72	.60	2.56
Lignite . . .	30.14	13.48	11.70	23.59	.88	3.32	14.22	—	—	—
Bituminous coal	34.32	14.62	22.94	14.85	1.42	1.16	10.97	—	—	—

Sulphur is an objectionable impurity in steaming coals on account of its corrosive action on the boiler tubes. It is also undesirable in coals to be used for metallurgical purposes and gas manufacture.

The following table gives the proximate analysis of a number of coals from different parts of the United States and Canada, the analyses being arranged according to grades.[1]

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[1] The type names are in each case those given in the reports from which analyses were taken.

PROXIMATE ANALYSES OF COAL

LOCALITY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	SULPHUR	FUEL RATIO
Peat						
Dismal Swamp, Va. . . .	20.22	52.31	24.52	—	—	.47
Orlando, Fla.	17.21	51.01	24.85	6.93	.49	.48
Salt-marsh peat, Maine . .	—	36.13	21.66	42.21	1.84	.57
Salt-marsh peat, Maine . .	—	29.88	12.31	57.81	2.19	.41
Washington Co., Me. (moisture free)	—	59.95	31.93	8.12	.47	.53
Lignite						
Lehigh, Stark Co., N. Dak. .	32.64	29.19	26.75	11.42	3.54	.91
Crockett, Houston Co., Tex.	34.70	32.23	21.87	11.80	.79	.67
Rockdale, Tex.	33.63	46.78	7.45	12.14	.99	1.51
Pickens Landing, Ala. . . .	12.40	42.20	36.60	8.80	—	.86
Pearl River, Scott Co., Miss.	13.50	39.66	36.50	10.34	(4.10)	.92
Kootznaboo, Alas.	2.41	44.75	47.93	4.88	.67	1.07
Upper Yukon, Rampart province, Alas.	11.42	41.15	36.95	10.48	.33	.91
Sub-bituminous						
Red Lodge, Carbon Co., Mont.	11.05	35.90	42.08	10.97	1.73	1.17
Weaver, N. Mex.	12.29	34.58	46.14	6.99	.63	1.33
Tesla, Alameda Co., Calif. .	18.51	35.33	30.67	15.49	3.05	.86
Cape Lisburne, Alas. . . .	9.35	38.01	47.19	5.45	.35	1.24
Bituminous						
Warrior, Jefferson Co., Ala. .	4.83	18.95	72.76	3.28	.17	3.83
Coking Coal, Raton field, Col.	.75	31.13	57.07	11.05	—	1.80
Yampa field, Col.	6.41	37.44	50.22	5.93	.60	1.30
Canyon City, Col.	6.21	31.32	52.47	11.10	—	1.65
Round Mountain, Ga. . . .	.615	21.011	75.956	1.94	.478	3.61
Lower Yukon, Alas. . . .	4.68	31.14	56.62	7.56	.48	1.90
Belleville, Ill.	5.50	39.50	54.60	5.40	—	1.38
Cannel Coal, Cannelburg, Ind.	1.47	49.08	26.35	23.10	1.48	.53
Block coal, Brazil, Ind. . .	13.82	35.16	49.96	1.06	1.47	1.42
Hartshorne, Okla.	1.68	41.00	51.91	5.41	2.72	1.26
Cannel Coal, Cumberland Gap field, Ky.	1.00	51.60	40.40	7.00	.739	.78
Fort Dodge, Ia.	7.48	39.52	45.54	8.44	5.28	1.15
Butler, Ky.	—	30.66	54.94	11.00	2.54	1.71
Owosso, Mich.	7.58	35.70	52.96	3.76	1.50	1.48
Verne, Mich.	5.82	39.79	45.15	9.24	3.83	1.13
Lexington, Mo.	9.24	29.01	42.19	15.18	4.38	1.45
Hocking Valley, Ohio . . .	5.93	36.48	52.41	5.13	1.09	1.44
Pittsburg coal, Connellsville, Pa.	1.26	31.79	57.79	7.16	.79	1.81
Jellico, Campbell Co., Tenn.	4.40	31.56	61.87	1.86	.31	1.96
Newcastle, Wash.	7.992	29.031	53.806	8.023	1.148	1.85
Coking Coal, Sydney Mines, N.S.	1.46	38.38	55.65	3.27	1.23	1.45
Inverness, N.S.	—	40.16	44.08	15.76	9.87	1.09
Semi-bituminous						
Johnson Co., Ark.	1.10	11.27	72.83	12.04	2.74	6.46
Coal Hill, Franklin Co., Ark. .	2.36	12.68	72.88	12.08	1.99	5.74
Garrett Co., Md.	2.33	16.11	68.43	13.13	1.49	4.24
Pocahontas, Tazewell Co., Va.	1.63	17.17	75.34	5.86	.75	4.38
Cape Lisburne, Alas. . . .	3.66	17.47	75.95	2.92	.96	4.46

PROXIMATE ANALYSES OF COAL—*Continued*

LOCALITY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	SULPHUR	FUEL RATIO
Semi-anthracite						
Spadra coal, Ark.	1.06	8.41	75.43	11.75	—	8.96
Bankhead, Alberta, Can. . .	.50	8.00	83.50	8.00	.14	10.43
Anthracite						
Crested Butte, Col.	1.58	6.70	87.46	4.26	.58	13.05
Cerrillos field, N. Mex. . . .	2.90	3.18	88.91	5.21	—	27.96
Mammoth seam, W. Middle Field, Pa.	3.163	3.717	81.143	11.078	.899	21.83
Mammoth seam, N. Middle Field, Pa.	3.421	4.381	83.268	8.203	.727	19.00
Yampa field, Col.	2.86	3.57	78.92	14.65	.59	22.1
Bering River, Alas.	7.88	6.15	78.23	7.74	1.30	12.86
Matanuska River, Alas. . .	2.55	7.08	84.32	6.05	.57	11.90

Origin of Coal (1–12). — It has been shown that there are gradations between unquestioned plant beds and mineral coal, and that coal, besides containing the same elements as plant tissue, often shows the presence of plant fibers, leaves, stems, seeds, etc., in addition to their occurrence in the associated rocks. Moreover, stumps or trunks of trees are sometimes found standing upright in the coal, with their roots penetrating the underlying bed of clay (6, 9), just as trunks of trees at present stand in bogs. While these facts point unmistakably to a vegetable origin of coal, it is less easy to understand the exact manner in which the great accumulations of vegetable matter have been made, and the changes from plant tissue to mineral coal. The several points, requiring explanation therefore are: (*a*) conditions of accumulation, (*b*) character of organisms forming coal, (*c*) conditions and duration of initial process of organic decomposition, and (*d*) nature of forces bringing about subsequent alteration of organic residues.

Conditions of Vegetable Accumulation (5, 9, 12). — At present there are several conditions under which plant remains accumulate to considerable depth over areas in some cases of large size. All of these are closely associated with water, either fresh or salt, because plant remains falling in water have their decay so retarded by the exclusion of air that accumulation is possible. Of these the following are the most important: (1) accumulation due to algæ on the sea bottom beneath a sargasso sea; (2) marine swamps, including salt marshes and mangrove swamps; (3) delta deposits; (4) peat bogs; (5) coastal-plain marshes.

While accumulations made in any one of these ways may form coal beds, and while individual beds may be formed which are due to any of these causes, to many of them there are such objections as to render them extremely improbable as general explanations for the great number of widely extended deposits of coal. The theory of accumulation from deposits of algæ, for example, demands deep water of an open ocean for the circulation of ocean currents. But most coal beds are evidently formed either on the land or else in shallow water of lakes, lagoons, or seacoast swamps.

To the theory of various swamps there are two serious objections: (1) that in such deposits as are now forming, the currents are bringing more fragmental sediments than are commonly present in coal beds; (2) that at present only one kind of tree, the mangrove, is adapted to growth in salt water. It is, of course, possible that in earlier ages the number of trees adapted to this mode of life was far greater.

The theory of the accumulation of vegetable matter in deltas is also open to serious objections. Streams are bringing plant remains to lakes or oceans, and incorporating them in their deltas; but nowhere are such extensive accumulations now forming as to make large coal fields in this manner. The perfect preservation of the plant remains in coal measures, upright trunks with roots extending into under clay, together with freedom from sediment, are against the theory that the coal is formed by accumulation of transported vegetable matter (*allochthonous origin*). And yet, as occasionally favoring this theory, we have coals without under clays, with abrupt clay partings, with marine shells, and even marine limestone immediately overlying the coal. In rare cases accumulations may have formed in quiet bays.

A more reasonable and widely accepted theory regards the vegetable matter to have accumulated by growth in place (*autochthonous origin*). It is a well-known fact that thick deposits of vegetable matter, often covering areas of several square miles, are formed in the peat bogs that in so many places represent the last stage of lake or pond filling. Each of these bogs would, under favorable circumstances, change to a bed of coal, and some of them are extensive enough to form coal beds of large size. But such bogs are, compared to our larger coal fields, far too limited in area to admit of the acceptance of this explanation to account for great coal fields without assuming far more widespread bog-forming conditions than any at present known.

Perhaps the most perfect resemblance to coal-forming condition is that now found on such coastal plain areas as that of southern Florida and the Dismal Swamp of Virginia and North Carolina. Both of these areas are very level, though with slight depressions in which there is either standing water or swamp conditions. In both regions there is such general interference with free drainage that there are extensive areas of swamp, and in both there are beds of vegetable accumulations. In each of these areas there is a general absence of sediment and therefore a marked variety of vegetable deposit. If either of these areas were submerged beneath the sea, the vegetable remains would be buried and a further step made toward the formation of a coal bed. Reëlevation, making a coastal plain, would permit the accumulation of another coal bed above the first, and this process might be continued again and again.

In support of the theory that coal was accumulated in some such situation as this, are a number of facts: (1) the coal beds occur over wide areas in sediments which were deposited near land borders and which may therefore have been again and again raised above sea level to form extensive coastal plains; (2) there are evidences of land conditions revealed in the workings of some mines; (3) the enormous area of some coal fields calls for some such widespread conditions as coastal plains might provide; (4) slight admixture of sediment indicates the absence of conditions of sediment supply, *e.g.* rivers, waves, tidal currents, and wind-formed currents; (5) vegetable accumulations made in such situations would require but slight changes in land level to be buried beneath sedimentary strata as the coal beds have been.

Character of Organisms forming Coal. — The view that coals are formed only of woody tissue or leaves is a popular one, but it is known that some cannel coals and splint coals are characterized by great numbers of spores and pollen grains, and a relatively small amount of woody matter. Boghead coals and oil shales have been found to be composed largely of remains of certain gelatinous algæ. It is often difficult to say, however, what proportion of some coals is woody matter and what is algal matter, but it is regarded by some that the latter may be the dominant factor in forming the properties of coal.

Conditions of Decomposition. — Two stages may be recognized in the coalification process, viz. (*a*) the putrefaction stage, which is a biochemical process, and (*b*) the alteration or metamorphic stage, involving dynamo-chemical action.

When dead vegetable matter accumulates under water, it does not remain unchanged, but undergoes a deoxygenation and dehydrogenation process, which is accomplished by fermentation or maceration in which minute plants (bacteria) and also animals take part. As a result of this the plant tissues break down into a somewhat jelly-like mass, the black peat, which jelly forms the amorphous ground-mass of coal and cements the plant tissues and sediment together.

The decomposition of the original cellulose ($C_6H_{10}O_5$) of the plant tissue liberates substances such as CH_4, as well as CO_2, CO, H_2O, etc. It seems probable that the jellification process leads no further than peat, and that for the development of the later stages dynamo-chemical changes are necessary.

While in peat beds the lower layers are under the gentle pressure of the upper layers, still peat is not changed even to lignite until buried under many feet of sediments. Indeed heat and pressure seem necessary for the change from lignite to bituminous coal, and long periods of time are apparently required for the slow changes that take place.

It has been commonly assumed that to produce the higher grades such as anthracite, strong folding was necessary, in order to develop sufficient heat and pressure for this degree of metamorphism. M. R. Campbell (2, 10) has, however, argued with apparent reason that while the chemical changes involved are induced by heat (of ordinary temperature), still these changes are retarded or prevented unless the structural conditions (presence of joints, etc.) are favorable for the escape of the gaseous products of this change.

Thus, for example, the Pennsylvania anthracites are formed not so much because of heat and pressure, but because of the cracking of the rocks which allowed thorough oxidation. The same amount of folding in the Pocono rocks of Maryland has not produced any anthracite, as the structural conditions were not favorable for the free escape of the gases.

Cases are known, where the heat causing the changes is intense and local, as in the Cerrillos coal field of New Mexico (80), or the Crested Butte district of Colorado (55), where bituminous coal has been locally changed to anthracite by a near-by igneous intrusion.

Some geologists, notably J. J. Stevenson, have argued that the anthracite coal has not been developed from bituminous coal by metamorphism, but that the volatile constituents were partly removed by longer exposure of the vegetable matter to oxidation before burial (11). Among paleobotanists there is also a difference of opinion as to whether the succession, peat, lignite, etc., is a strictly lineal one.

The following theory of coal formation has recently been advanced by Dowling (4). The death of a plant is marked by the loss of power to form oxidized hydrocarbon compounds, consequently chemical reactions are set up in the material of the dead plant. The formation of compounds of oxygen and carbon is the first evidence of decay. With the escape of these gases the hydrocarbons left behind become unstable, and loss of marsh gas follows. If fermentation accompanies decay, new hydrocarbon compounds are formed by this parasitic form of life and the reduction of oxygen is accomplished without great loss of hydrogen which is the element that gives character to the material, especially when in the coal stage. When solidified by superposed load, the fermentation is arrested and pressure and heat cause the subsequent alteration. Static pressure favors the combination of oxygen with carbon or hydrogen. Heat causes the combination of carbon with oxygen or hydrogen. Pressure effects the alteration without loss of carbon, while heat wastes it.

Chemical Changes. — The chemical changes referred to above may be illustrated by the following chemical equations (19, p. 26):

VEGETABLE TISSUE = LOSS BY DECOMPOSITION COALS

$$(1)\quad \underset{\text{Cellulose}}{5\,C_6H_{10}O_5} = \underset{\text{Carbon oxides}}{6\,CO_2 + CO} + \underset{\text{Marsh gas}}{3\,CH_4} + \underset{\text{Water}}{8\,H_2O} + \underset{\text{Lignite}}{C_{20}H_{22}O_4}$$

$$(2)\quad \underset{\text{Cellulose}}{6\,C_6H_{10}O_5} = \underset{\text{Carbon dioxide}}{8\,CO_2} + CO + \underset{\text{Marsh gas}}{5\,CH_4} + \underset{\text{Water}}{10\,H_2O} + \underset{\text{Bituminous}}{C_{22}H_{20}O}$$

$$(3)\quad \underset{\text{Cellulose}}{7\,C_6H_{10}O_5} = \underset{\text{Carbon dioxide}}{8\,CO_2} + \underset{\text{Marsh gas}}{4\,CH_4} + \underset{\text{Water}}{19\,H_2O} + \underset{\text{Semi-bituminous}}{C_{30}H_{16}O}$$

These equations are not intended to indicate that there is necessarily a direct passage from cellulose to semi-bituminous coal, without the development of intermediate stages; and to bring out this lineal succession as well as to show the changes by a graphical method we may use the following diagram (Fig. 1) prepared by the late Professor Newberry.

In this diagram the rectangle *ABCD* represents a given volume of fresh vegetable matter, which contains a small percentage of mineral matter, the rest being organic substances consisting roughly of 50 per cent carbon (*EFCD*) and 50 per cent hydrogen, oxygen, and nitrogen (*ABEF*). In the change from fresh vegetable tissue to peat, part of these four elements pass off as gaseous compounds, so that the remaining volume of peat is less (*BGD H*) than the original volume of vegetable matter (*ABCD*).. Since, however, H, O, and N have passed off in larger amounts than the carbon, the percentage of the latter in the peat will be higher than it was in the fresh plant tissue. (Compare *BFGI* and *FID H* with *ABEF* and *EFCD*.) The actual weight of mineral matter will be the same, but its percentage will be larger. This change, continued, will result finally in anthracite, the last of the coal series, in which the per cent of carbon (*LKM N*) is high and that of the other organic elements low (*J KL*). The amount of compression that occurs in such changes as those illustrated in the diagram may be understood when it is stated that it is estimated that from 16 to 30 feet of peat are required to make one foot of true coal.

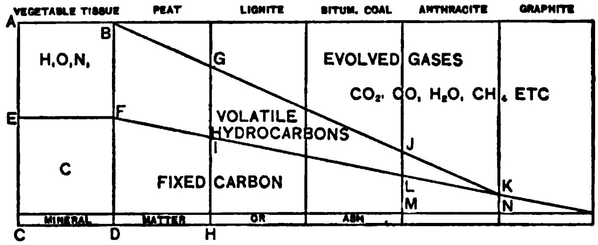

FIG. 1. — Diagram showing changes occurring in passage of vegetable tissue to graphite. (*After Newberry.*)

The following elementary analyses of peat, lignite, and various grades of coal clearly illustrate this gradual concentration of carbon by losses of volatile elements.

ELEMENTARY ANALYSES OF COALS

KIND	C	H	O	N	S	ASH	MOISTURE
Peat	59.47	6.52	31.51	2.51	—	—	22
Lignite	52.66	5.22	27.15	.71	2.02	12.24	—
Sub-bituminous . . .	58.41	5.06	28.99	1.09	.63	4.79	—
Bituminous	82.70	4.77	9.39	1.62	.45	1.07	—
Semi-bituminous . . .	83.14	4.58	4.65	1.02	.75	5.86	—
Anthracite	90.45	2.43	2.45	—	—	4.67	—

Classification of Coals. — At the present time a number of kinds of coal are recognized in the United States and Canada, whose differentiation depends on their physical and chemical properties. But even these few type names are often used in a rather loose way.

Perhaps the first important attempt at classification was that of P. Frazer, Jr., based on the fuel ratio (17). This was as follows: —

	Fuel Ratio
Anthracite	100–12
Semi-anthracite	12– 8
Semi-bituminous	8– 5
Bituminous	5– 0

Objections which have been urged against this are that all coals with a fuel ratio of less than 5 are grouped into one class and no provision made for lignite. It also groups good and poor bituminous coals together.

Collier (15) proposed that all coals having a moisture content of over 10 per cent should be classed as lignite and those with less as bituminous, but this differentiation has been shown to be unreliable.

M. R. Campbell, while agreeing to the usefulness of the fuel ratio classification for coals above the bituminous grade, criticised its application to coals of this type or lower ones, and suggested a provisional classification based on the carbon-hydrogen ratio (14).[1]

Group	$\frac{C}{H}$
A (Graphite)	∞
B, C Anthracite	?–30 (?)
D Semi-anthracite	26 (?)–23 (?)
E Semi-bituminous	23 (?)–20
F Bituminous	20–17
G	17–14.4
H	14.4–12.5
I	12.5–11.2
J Lignite	11.2–9.3
K Peat	9.3–?
L Wood	7.2

This table is likewise faulty, as it does not completely separate the peats, lignites, sub-bituminous, and even some of the bituminous coals.

Parr (19), in attempting to make a satisfactory classification, points out that the term *volatile combustible* is incorrect as it consists of combustible hydrocarbons and noncombustible H, O, and N. Thus in a Pocahontas coal with 18.70 per cent volatile combustible, 14.5 per cent is hydrocarbons and 4.2 per cent hydrogen, oxygen, and nitrogen. Again, a North Dakota lignite had 41.91 per ent volatile combustibles, made up of 20.28 per cent hydrocarbons and 21.63 per cent hydrogen, oxygen, and nitrogen. In a logical classification, therefore, allowance should be made for this inert volatile matter.

In Parr's classification the terms used are: *vc*, or volatile carbon unassociated with hydrogen, obtained from $C - fc$ (total carbon minus fixed carbon);

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[1] Campbell found that subdivisions based on total carbon, total hydrogen, and calorific value were all unsatisfactory.

C, or total carbon as determined by analysis; and *inert volatile matter*, obtained by subtracting from 100 per cent the sum of total carbon, available hydrogen,[1] sulphur, ash, and water.

It will be seen that Parr's classification, which follows, requires data from both the elementary and the proximate analysis of the coal.

PARR'S CLASSIFICATION.

Coals	Anthracitic	Anthracites Proper		Ratio $\frac{vc}{C}$ below 4 %.
		Semi-Anthracite		Ratio $\frac{vc}{C}$ between 4 % and 8 %.
		Semi-Bituminous		Ratio $\frac{vc}{C}$ from 10 % to 15 %.
	Bituminous	Bituminous Proper	A	Ratio $\frac{vc}{C}$ from 20 % to 32 %. Inert volatile from 5 % to 10 %.
			B	Ratio $\frac{vc}{C}$ from 20 % to 27 %. Inert volatile from 10 % to 16 %.
			C	Ratio $\frac{vc}{C}$ from 32 % to 44 %. Inert volatile from 5 % to 10 %.
			D	Ratio $\frac{vc}{C}$ from 27 % to 44 %. Inert volatile from 10 % to 16 %.
		Black Lignites		Ratio $\frac{vc}{C}$ from 27 % up. Inert volatile from 16 % to 20 %.
		Brown Lignites		Ratio $\frac{vc}{C}$ from 27 % up. Inert volatile from 20 % to 30 %.

Grout's classification (18) is expressed by the formula:

$$\frac{\text{Fixed carbon}}{100 - \text{Fixed carbon}},$$

based on pure coal. He makes the following classes: —

Graphite	Fixed carbon, over 99 per cent.
Anthracite	Fixed carbon, over 93 per cent.

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[1] That part of hydrogen content, excluding the hydrogen united with oxygen to form water, which is free to enter into combustion with oxygen for the production of heat.

Semi-anthracite	Fixed carbon, 83 per cent to 93 per cent.
Semi-bituminous	Fixed carbon, 73 per cent to 83 per cent.
Bituminous	
High grade	Fixed carbon, 48 per cent to 73 per cent. Total carbon, 82 per cent to 88 per cent.
Low grade	Fixed carbon, 48 per cent to 73 per cent. Total carbon, 76.2 per cent to 82 per cent.
Cannel	Fixed carbon, 35 per cent to 48 per cent. Total carbon, 76.2 per cent to 88 per cent.
Black lignite	Fixed carbon, 35 per cent to 60 per cent. Total carbon, 73.6 per cent to 76.2 per cent.
Brown lignite	Fixed carbon, 30 per cent to 55 per cent. Total carbon, 65 per cent to 73.6 per cent.
Peat and turf	Fixed carbon, below 55 per cent. Total carbon, below 65 per cent.
Wood	

D. B. Dowling (16) notes that one objection to Campbell's $\frac{C}{H}$ classification is the necessity for having an elementary analysis, which is rarely made, costly, and time requiring. As a substitute for Campbell's classification, he substitutes what he has provisionally termed the "split volatile ratio" viz.

$$\frac{\text{Fixed carbon} + \frac{1}{2}\text{ volatile combustible}}{\text{Moisture} + \frac{1}{2}\text{ volatile combustible}}.$$

An arrangement of a series of coals by this method and also Campbell's $\frac{C}{H}$ ratio does not indicate great disagreement; moreover, Dowling's classification has the advantage of being based on the proximate composition. He makes the following subdivisions: —

Group.	Split Vol. Ratio
Anthracite	15 up
Semi-anthracite	13–15
Anthracite coal	10–13
High carbon bituminous	6–10
Bituminous	3.5–6
Low carbon bituminous	3–3.5
Lignitic coal	2.50–3
Lignite	1.20–3.50

More recently, Campbell has suggested the recognition of two classes of coal below bituminous, calling the upper grade "sub-bituminous" and the lower grade "lignite." He suggests that the manner of weathering be used as a criterion for separating the bituminous from the sub-bituminous, the former cleaving into prisms, while the latter checks irregularly on drying, and when weathered on the outcrop cleaves into plates parallel to the bedding. The sub-bituminous coals with their black color he claims can be distinguished from lignites, because the latter are brown.

White's Classification. — White (20) has shown that if a series of coals of different ages, kinds, and regions are plotted according to the C : (O + ash) ratios and calorific values as components, they describe a curve, which shows a close relation between the increase of the above mentioned ratio and the calorific power. Weathered coals, those having over 78 per cent fixed carbon in pure coal, and the boghead-cannel group (high in hydrogen) are the greatest variants. Oxygen is ranked with ash in this ratio because the two are approximately equal in anti-calorific potency. This ratio cannot be used as a basis for separation into kinds, such as peat, lignite, etc.

Structural Features of Coal Beds. — *Outcrops* (24, 25). — The outcrop of a coal bed is usually easily recognizable on account of its color and coaly character; but unless the exposure is a rather fresh one, the material is disintegrated and mellowed, the wash from it mingling with the soil, and if the outcropping bed is on a hillside, often extending some feet down the slope. This weathered outcrop has been termed the "smut" or "blossom" by coal miners. In areas where the beds have been tilted and the slopes are steep, the outcrops of coal can usually be easily traced; but in regions where the dip is low and the surface level, the search for coal is often attended with difficulty, which is increased if the country is covered with glacial drift. In such cases boring or pitting is commonly resorted to.

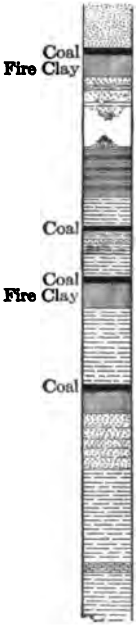

FIG. 2. — Section in coal measures of western Pennsylvania, showing fire clay under coal beds. (*After Hopkins.*)

The number of coal beds found in any given region varies, and may at times be large. Thus in the Pennsylvania section, as many as 20 beds are known; in Alabama, at least, 55 have been counted, but not all are workable; while in Indiana there are 25, of which 9 are minable over large areas. The beds are rarely parallel, and, moreover, thin out if followed any distance.

Associated Rocks. — Most coal beds are interbedded with shales, clays, or sandstones, though conglomerates or limestones are at times also found in close proximity. Coal beds are often underlain by a bed of clay, which in some regions is of refractory character (Fig. 2); but the widespread belief that all these under clays are fire clays is unwarranted.

Variations in Thickness.—Coal beds or "seams" are rarely of uniform thickness over large areas; indeed, a bed which is of sufficient thickness to work in one mine may be so thin in a neighboring one as to be scarcely noticeable. This irregularity is in some cases due to variations in thickness of vegetable accumulations, in other cases to local squeezing of the coal bed subsequent to its formation.

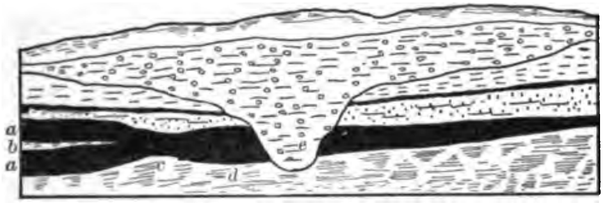

Fig. 3. — Section showing irregularities in coal seam. ***a***, **split;** ***b***, **parting of shale;** ***c***, **pinch;** ***d***, **swell;** ***e***, **cut out.**

These thinnings and thickenings are commonly called "pinchings" and "swellings" (Fig. 3). In regions of pronounced folding, the beds are usually found in separate synclinal basins, the intervening anticlinal folds having been worn away.

Other Irregularities. — Splitting (Fig. 3) is a common feature of many coal seams. The Mammoth bed, so prominent in most of the anthracite basins of Pennsylvania, splits into three separate beds in the Wilkesbarre basin. This splitting is caused by the appearance of beds of shale (called "slate" by coal miners), which often become so thick as to split up the coal seam into two or more beds. When narrow, such a bed of slate is called a parting. The Pittsburg seam of western Pennsylvania shows a fire-clay parting or "horseback" from six to ten inches thick over many square miles.

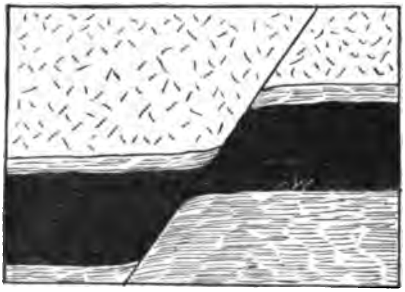

Fig. 4. — Section of faulted coal seam. (*After Keyes, Ia. Geol. Surv., II.*)

An interesting case of parting is found in the 13-foot seam at Inverness, Nova Scotia. At the outcrop this showed three shale partings, of 1 foot, 9 inches, and 11 inches respectively. At 2500 feet down the dip, these partings had increased to 19, 3, and 22 feet respectively. A 7-foot seam, lying 284 feet below the 13-foot one, maintained its thickness, however, for this same distance on the dip.

In addition to these "slate" partings, which run parallel with the bedding, others are often encountered which cut across the beds from top to bottom. These in some cases represent erosion channels formed in the coal during or subsequent to its formation, and later filled by the deposition of sand or clay. In other cases they are due to the filling of fissures formed during the folding of the strata.

Coal beds may pass into shale, the latter representing possibly islands of mud or ridges which arose above the level of the marsh in which the coal plants accumulated.

Faulting (Fig. 4) is not an uncommon feature of coal beds, and the coal is sometimes badly crushed on either side of the line of fracture. The amount of throw and the number and kinds of faults may vary, so that one might expect normal, reverse, overthrust, and even step faults.

Weathering of Coals. — Parr and Hamilton (27), as a result of their investigations of the weathering of coal, concluded that submerged coal does not lose appreciably in heat value, but that outdoor exposure results in a loss of heating value varying from 2 to 10 per cent. Dry storage is only of advantage for high sulphur coals, where the disintegrating effect of sulphur in process of oxidation facilitates escape of hydrocarbons by oxidation of the same. Storage losses usually appear to be complete at end of five months.

Coal Fields of the United States.[1] (Pl. I.) — Coal in commercial quantities occurs in thirty-three states and territories, as well as in Alaska. These occurrences can be grouped into the following fields: —

	AREA, SQ. MI.
(1) *Appalachian*, including parts of Pennsylvania, Ohio, Maryland, Virginia, West Virginia, Eastern Kentucky, Tennessee, Georgia, and Alabama	69,812
(2) *Atlantic Coast Triassic*, including parts of Virginia and North Carolina	210
(3) *Eastern Interior*, including parts of Indiana, Illinois, and western Kentucky	48,500
(4) *Northern Interior*, including parts of Michigan	11,000
(5) *Western Interior*, including parts of Iowa, Missouri, Nebraska, Kansas, Oklahoma, and Arkansas	71,664
(6) *Southwestern field*, including parts of Texas	13,500
(7) *Gulf Coast Lignite field*, including portions of Alabama, Mississippi, Louisiana, Arkansas, and Texas	84,300
(8) *Rocky Mountain field*, including parts of Colorado, Arizona, New Mexico, Utah, Wyoming, Idaho, Montana, North Dakota, South Dakota	195,960
(9) *Pacific Coast Field*, including parts of Washington, Oregon, and California	1,830
	486,576
(10) *Alaska*	

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[1] The Rhode Island area of graphitic anthracite, formerly included in this list, is referred to under Graphite.

The estimates of areas given above are from calculations made by the United States Geological Survey, and are to be regarded as fairly accurate, but some of these fields may be extended in the future by the development of areas now classed as unproductive. This applies especially to those in which the coal lies too deep to be profitably mined at present. It is a noteworthy fact that the production of the fields is by no means proportional to their areas (compare above list with table, p. 39). Proximity to markets, value of the coal for fuel, and relative quantity of coal per square mile of productive area are factors of importance in determining the output of a field.

Geologic Distribution of Coals in the United States. — The coal-bearing formations of the United States range in age from Carboniferous to Tertiary. The Carboniferous coals occur east of the 100th meridian and on the whole include the the best coals of the country. The higher grades occur in the anthracite regions of Pennsylvania and Arkansas. Cretaceous coals lie between the 100th and 115th meridian, and Tertiary coals chiefly between the 120th meridian and the Pacific coast. Exceptions to this distribution are the occurrence of a small area of Triassic coals in Virginia and North Carolina, and a large area of Tertiary lignites in the Gulf states. This indicates that during the coal-forming periods there was in North America a slow westward shifting of the zone in which conditions favorable to coal formation occurred, the only exceptions being those mentioned above.

The Carboniferous coals are commonly grouped into several well-marked and clearly separated areas; but this isolation is probably the result of folding and erosion, all excepting the Michigan field having apparently been originally continuous.[1] To a certain extent the same is true of the Rocky Mountains coal fields. These have often been seriously disturbed by post-Cretaceous uplifts which in many instances have improved the qualities of the coal. As a whole, the Tertiary coals are medium to low grade, though in some sections, notably in Washington, they are of excellent quality.

Estimated Tonnage of the Various Fields. — Much attention has been given in the last few years to the necessity of conserving the coal supply, for this material has been mined in a wasteful manner. The following table gives the estimate prepared by the United States Geological Survey, the quantity of coal contained in the several fields being given:[2] —

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[1] Ashley, Econ. Geol., II : 659, 1907.

[2] This grouping is somewhat different from that adopted in this book and indeed by most writers.

Tonnage (Short Tons) by Provinces and Accessibility

Province	Area	Original Coal Supply		Total
		Amount Easily Accessible	Amount Accessible with Difficulty	
	Sq. Miles	Tons	Tons	Tons
1. Eastern .	70,022	555,634,000,000	8,000,000,000	563,634,000,000
2. Interior .	144,664	406,667,000,000	91,000,000,000	497,667,000,000
3. Gulf . .	84,300	13,045,000,000	10,045,000,000	23,090,000 000
4. Northern or Great Plains .	103,564	521,793,000,000	459,000,000,000	980,793,000,000
5. Rocky Mountain	92,396	414,740,000,000	574,280,000,000	989,020,000,000
6. Pacific Coast .	1,830	11,100,000,000	10,900,000,000	22,000,000,000
Total .	496,776	1,922,979,000,000	1,153,225,000,000	3,076,204,000,000

The distribution of this original supply of coal, according to grades and accessibility, is also shown below.

Tonnage (Short Tons) by Grades of Coal and Accessibility

Kind of Coal	Area	Original Coal Supply		
		Amount Easily Accessible	Amount Accessible with Difficulty	Easily Accessible and Available
	Sq. Miles	Tons	Tons	Tons
Anthracite and bituminous .	250,531	1,176,727,000,000	505,730,000,000	1,176,727,000,000
Sub-bituminous .	97,636	356,707,000,000	293,450,000,000	216,252,000,000
Lignite . .	148,609	389,545,000,000	354,045,000,000	
Total . .	496,776	1,922,979,000,000	1,153,225,000,000	1,392,979,000,000

It should be said that the limit of workable depth, based on foreign experience, is 3000 feet for coal and 1000 feet for lignite. Twenty inches is regarded as the minimum minable thickness of bed for coal and 3 feet for lignite. If the rate of increase which has held for the last fifty years is maintained, the supply of easily available coal will be exhausted before the middle of the next century.

Appalachian Field (33, 36, 39, 91, 99, 100, 101, etc.). — This, the most important coal field in the United States, extends 850 miles, from northeastern Pennsylvania to Alabama. It shows

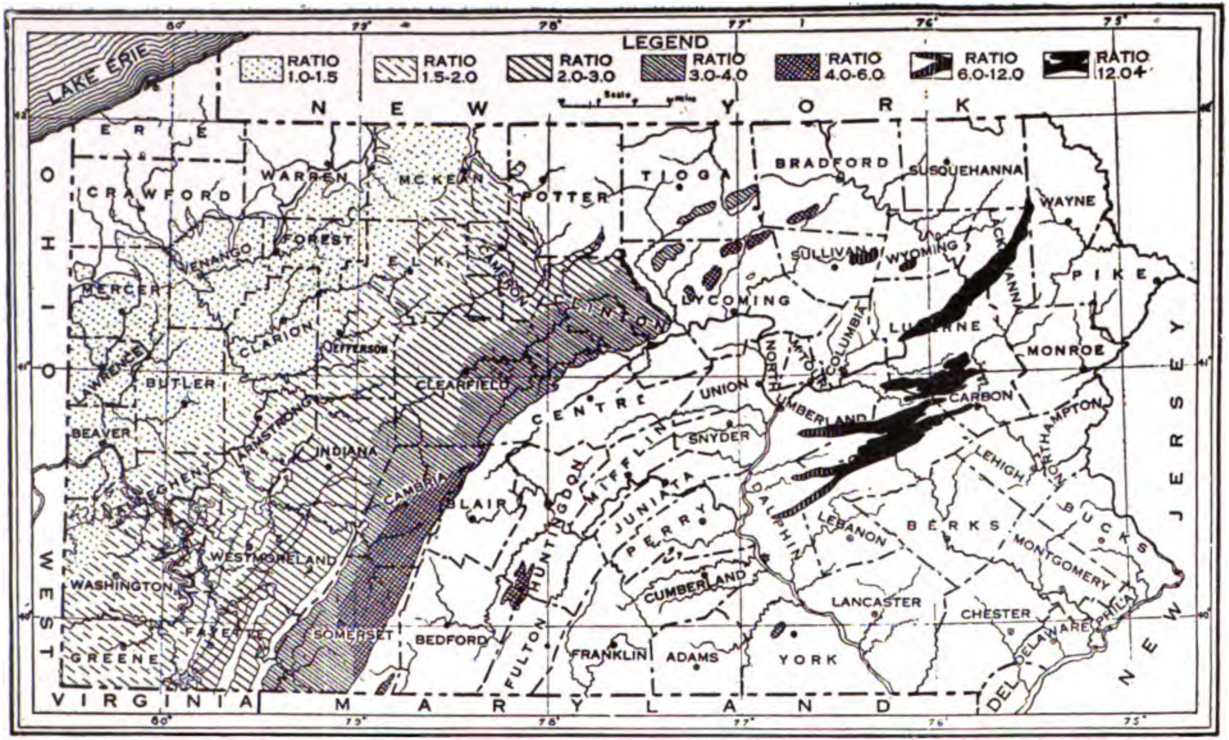

Plate II. — Map of Pennsylvania, showing distribution of coals by fuel ratios. (*Pa. Geol. and Top. Com. Rept.*, 1906–1908.)

a maximum of 180 miles at the northern end, narrows to less than 30 miles in Tennessee, and expands again to 85 miles in Alabama. About 75 per cent of its area contains workable coal. At the southern end the coal measures pass beneath the coastal plain deposits, and they may connect with the Arkansas Coal Measures beneath the Mississippi embayment.

Being closely associated with the Appalachian Mountain uplift, the coal measures of this region partake of the structural features of the Appalachian belt. The eastern margin of the field borders on a belt of steeply folded strata, forming the Appalachian Valley, and hence the coal-bearing formations are much folded here (Fig. 5, 9), while at the southern end of the field they are faulted in addition (Fig. 5). Extensive erosion following the folding of the coal measures has resulted in the development of a number of basins.

The coal measures of the Appalachian field consist of a great thickness of overlapping lenses of conglomerate, sandstone, limestone, shale, fire clay, and coal. The formations in general show a thinning from the eastern margin of the field, westward, as well as showing a decrease in the number and thickness of the beds. Owing to the lenticular character of the deposits, and the local thickenings, it is difficult to trace individual beds of coal over wide areas, or correlate sections at widely separated points.

The middle Carboniferous or Pennsylvanian includes most of the coal beds of the Appalachian field, but there are some also in the upper Carboniferous and in the Pocono of the lower Carboniferous or Mississippian.

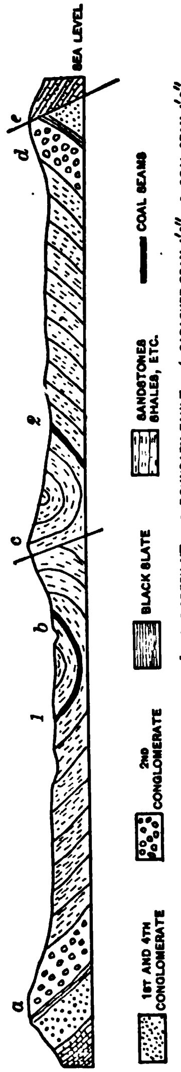
SEA LEVEL
a
b
c
d
e
1
2
1ST AND 4TH CONGLOMERATE
2ND CONGLOMERATE
BLACK SLATE
SANDSTONES SHALES, ETC.
COAL SEAMS
a. BALD ROCK b. CANE CREEK c. VERTICAL MEASURES d. WOLF CREEK MT. e. BOUNDARY FAULT 1. CARACKER SEAM 4'-0" 2. COAL SEAM 4'-0"

FIG. 5. — Section across Coosa coal field, Alabama, showing folding and faulting characteristics of southern end of Appalachian coal field. (*After Gibson, Ala. Geol. Surv.*, 1895.)

The classic section of the Coal Measures, first worked out in Pennsylvania, was as follows: —

(1) Dunkard or Upper Barren Measures.

(2) Monongahela or Upper Productive Measures.

(3) Conemaugh or Lower Barren Measures.
(4) Alleghany or Lower Productive Measures.
(5) Pottsville conglomerate.

At the time it was made the second and fourth members were thought to be the only ones carrying coal, and hence the name "Productive"; but since then the Pottsville has been found to be locally productive, and a few seams have been found even in the Barren Measures. By some the Dunkard series is now placed in the Permian.

The divisions named above are recognizable also in Ohio, West Virginia, and Maryland, but farther south the identification of all becomes difficult.

The Appalachian field is divisible into two parts of very unequal size, viz. (1) the anthracite field of northeastern Pennsylvania; and (2) the bituminous area, which occupies the balance of the field.[1]

Pennsylvania Anthracite Field (100). — This field (Fig. 6) lies in the central part of the state, covering an area of about 3300 square miles, about one-seventh of which is underlain by workable coal measures. The field has four main subdivisions, known respectively as the northern, eastern middle, southern, and western middle. Intense folding (Fig. 7) has placed some of the coal in synclinal troughs, where it has been preserved from erosion which has removed the coal from the intervening anticlines. Therefore the anthracite is found in a number of more or less separated narrow basins. It has been estimated that from 94 to 98 per cent of the coal originally deposited has been removed from this field by denudation.

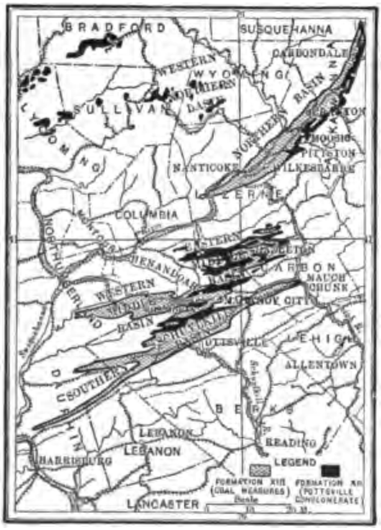

FIG. 6. — Map of Pennsylvania anthracite field. (*After Stoek, U. S. Geol. Surv., 22d Ann. Rept., III.*)

The Coal Measures of the anthracite district consist of beds of sandstone, shale, and clay, with coal beds at intervals varying from a few feet to several hundred feet, though rarely exceeding 200 feet. The coal beds, which vary in thickness from a few inches to 50 or 60 feet, occur throughout the entire section of the Coal Measures, but are most important in the lower 300 to 500 feet. Among these the Mammoth is of importance, but splits in some areas.

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[1] This includes some small areas of semi-anthracite.

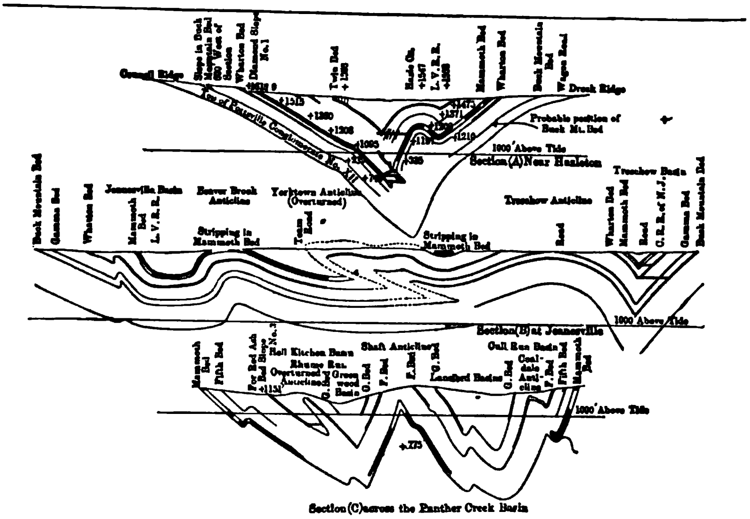

FIG. 7. — Sections in Pennsylvania anthracite field. (*After Stoek, U. S. Geol. Surv., 22d Ann. Rept., III.*)

The anthracite section, though not yet accurately correlated with the bituminous field of Western Pennsylvania, is nevertheless known to contain the Pocono, Mauch Chunk, Pottsville, and Alleghany series, as well as some of the higher ones of the Coal Measures (39). The Pottsville conglomerate forms an important stratigraphic horizon, recognizable by its lithological characters and bold outcrops.

The position of the coal beds and physical characteristics of the coal have necessitated the use of special methods of mining and of treatment after mining (100). Sharpness of folding and steep dips prevail, these introducing many mining problems not found in bituminous regions. When brought to the surface, the anthracite consists of lumps varying in size and mixed with more or less shaly coal called *bone*, so that before shipment to market it is necessary to break, size, and sort it. This is done in a *coal breaker* (Fig. 8), in which the coal is crushed in rolls and sized by screens, while the slate is separated either by hand, automatic pickers, or jigs. These breakers are a prominent feature of the anthracite region, and much money has been spent in increasing their efficiency. As the result of years of mining, the refuse from the breakers, consisting of a fine coal-dust and bone, termed "*culm*," has accumulated in enormous piles. Much of it is now being washed to save the finer particles of clean coal; and much is also washed into the mines to support the roof, so that the pillars of coal, originally left for that purpose, can be extracted.

On account of its cleanliness and high fuel ratio, anthracite coal is much prized for domestic purposes. Most of that mined is marketed in the eastern and middle states, although small quantities are shipped to the western states, especially those that can be reached by way of the Great Lakes.

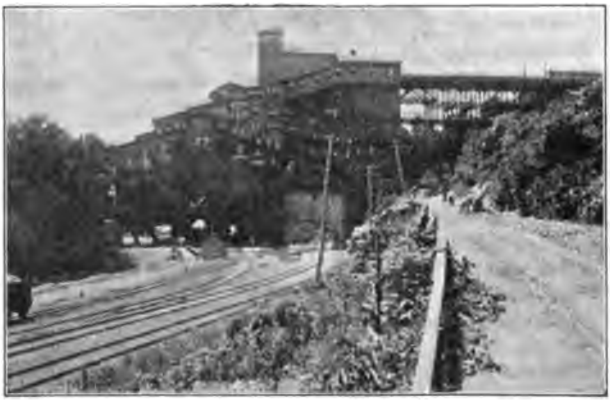

FIG. 8. — Coal breaker in Pennsylvania anthracite region.

Appalachian Bituminous Area (36, 41). *Pennsylvania.* — The Pennsylvania bituminous field includes an area of about 12,000 square miles lying mostly in the western part of the state (Pl. II), and having an exceedingly irregular boundary. In the northwestern part, where folding is slight, the coal measures form outliers, capping the high hills and ridges; but to the eastward, the more marked synclinal structure has resulted in the formation of a strung out series of basins. The most northeastern areas are quite isolated, and include the Bernice (semi-anthracite), Barclay, and Blossburg basins, as well as an easterly one, the Broadtop (Pl. II).

The coals range in age from Pottsville to Dunkard, and in about four-fifths of the territory the thickness of the Upper Carboniferous rocks, including Dunkard, is less than 1000 feet, while in one-third it is under 500 feet (41). Faults are rarely found. On account of the variation in thickness of the sandstones and other rocks, splitting of coal seams, and other irregularities, correlation is difficult. But in a general way the beds above the Pittsburg seam appear to be more regular in their appearance and more constant in their dis-

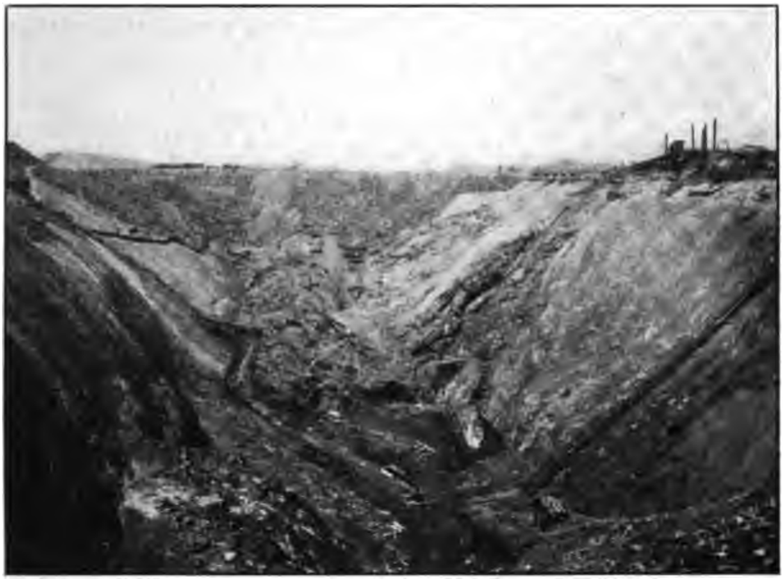

FIG. 1. — Pit working (strippings) near Milnesville, Pa. The Mammoth seam is uncovered in bottom of pit.

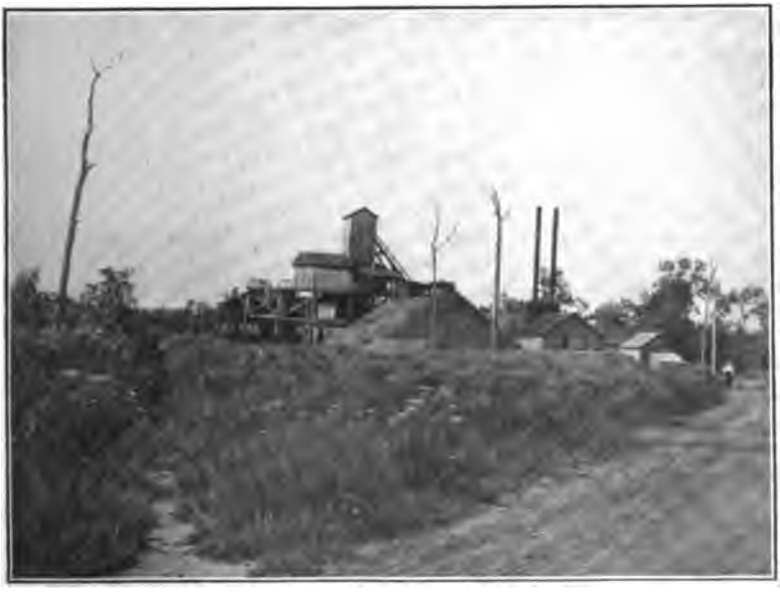

FIG. 2. — View in Arkansas coal field. (*H. Ries, photo.*)

tance from one another, than the beds in the lower part of the section. The number of coal seams recognized in the several series is as follows (99): —

Dunkard series,	1100–1200 feet thick,	12 coals
Monongahela,	200– 300 feet thick,	6 coals
Conemaugh,	500– 700 feet thick,	6 coals, mostly unimportant
Alleghany,	300 feet thick,	4 coals
Pottsville,		several

The Alleghany yields about forty per cent of the bituminous coals mined in Pennsylvania. While most of the coal beds are of limited extent, the celebrated Pittsburg seam at the base of the Monongahela has an average thickness of 7 feet over about 2100 square miles of its area and an estimated tonnage of 9,641,792,907 short tons, thus making it one of the most important bituminous coal beds in the world. This same seam is also recognizable and important in Ohio, West Virginia, and Maryland.

Ohio. — In Ohio (40, 90–92) the five subdivisions of the middle and Upper Carboniferous are also recognized, and there are at least 16 coal beds, of which 6 are important. These include the Pomeroy,[1] Pittsburg, Meigs (Sewickley of Pennsylvania), Clarion, Lower Kittanning, Middle Kittanning, Upper Freeport, Wellston, and Block (Sharon). The Pittsburg coal is of high importance and the Middle Kittanning includes the well-known Hocking Valley coal.

Maryland. — In Maryland the coals lie in three broad northeast-southwest synclinal folds, the coal measures of these being separated by Mississippian or Devonian Rocks, exposed by erosion of the intervening anticlines. The eastern or Potomac basin is the most important of the three. The geologic position and number of coals is as follows: Monongahela, with Pittsburg (Elk Garden), Tyson, and Koontz coals; Conemaugh, 2 coals; Alleghany with Upper Freeport (Thomas or three foot), Middle Kittanning (Davis or six foot), Brookville (Parker), and Clarion (Bluebaugh); Pottsville, with two seams. The coals are good steaming fuels and will coke.

West Virginia. — In this state the Coal Measures occupy an irregular rectangle extending from the Alleghany Mountain region northwestward to the Ohio River. The deepest part of the Appalachian basin takes a southwest course across the state, the axis rising to the southward. From this the strata rise to the northwest, while to the southeast the basin shows a series of folds of increasing steepness and height towards the eastern boundary of the fields.

The coal beds range from the Pocono to the Dunkard in age. The Pocono contains some unimportant beds of anthracite along the eastern border of the field, but westward the formation is noted for its petroleum and absence of coal.

The Pottsville carries the coals of the New River and Pocahontas series,

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[1] Formerly regarded as Pittsburg, but shown by Bownocker to be equivalent of Redstone of Pennsylvania and West Virginia. (Ohio Geol. Surv., 4th ser., Bull. 9, p. 96, 1908.)

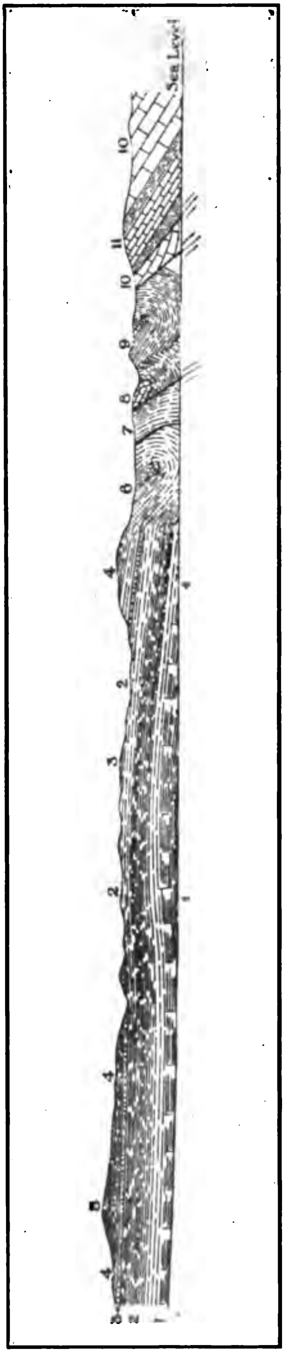

Fig. 9. — Structure section in Tazewell County, east of Richlands, southwest Virginia coal field. 1–8, Carboniferous; 9, Devonian; 10, Cambro-Silurian; 11, Cambrian. (*From Min. Res. Va.*, 1907.)

these underlying an area of about 2600 square miles in the southeastern and eastern part of the field. These coals are of high quality, being low in sulphur and ash. In northern West Virginia the Alleghany series carries several coal beds, but with one exception these disappear to the southwestward. The Conemaugh carries two coal beds of importance, while the Monongahela carries six distinct beds, including the famous Pittsburg seam. No coals of much importance are found in the Dunkard.

Virginia (111). — The coals of the Mountain Province are of either Mississippian or Pennsylvanian age. The first or least important forms a belt of small areas of either semi-bituminous or semi-anthracitic character extending from Wythe to Frederick counties, but the only one of much importance is the Montgomery-Pulaski county area.

The Pennsylvania coals lie in the extreme southwestern part of the state in the Cumberland Plateau region, and are the most important producers. The two chief fields are the Pocahontas or Flat Top and the Big Stone Gap coal fields.

The coal measures, which are probably mostly of Pottsville age, show comparatively little disturbance, although they lie immediately west of the highly folded rocks of the Great Valley (Fig. 9), but the Pocahontas field is abruptly terminated on the east by a fault. In the Pocahontas field there are at least six workable beds; the coal is of excellent quality for steaming purposes, shows often a remarkably low ash content, and makes a good coke. The Big Stone Gap field, which extends into Kentucky, contains eight workable seams and is even a more important producer of coal and coke.

Southern Appalachian Field. — In the southern Appalachian field the coal-bearing rocks are mainly of

Pottsville age, and in the Birmingham, Ala., district have a thickness of probably 5000 to 6000 feet. The Coal Measures, which show much disturbance on their eastern margin, with but little toward the west, are divisible into a lower (Lee, Lookout, or Millstone Grit) group, carrying about three thin seams in the lower part, and an upper group, with many beds of coal.

Although the coals and associated rocks were originally deposited in a broad trough, this has been subsequently folded, and faulted, while the basins are separated partly by faulting and partly by erosion of intervening anticlinal crests.

There are three main districts, known as the Jellico, Chattanooga, and Birmingham, the latter containing four fields, viz., the Warrior, Coosa, Cahaba, and Blount Mountain.

The Triassic Field (111, 112). — This coal field, which is more important historically than economically, having been worked as early as 1700, includes several small steep-sided basins (Fig. 10), lying in the Piedmont region of Virginia and North Carolina. It is probable that the coal-bearing beds of the several areas, originally horizontal, were formerly continuous, having been separated by folding, faulting, and denudation. In addition to this, the coal is cut by dikes and sheets of igneous rock, which have locally altered it to natural coke or *carbonite*.

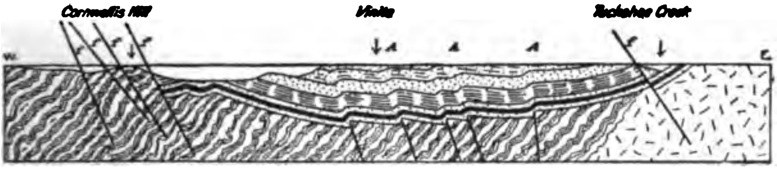

FIG. 10. — General structure section of the Richmond Basin in the vicinity of James River. *A*, *A*, *A*, minor flexures, with beds downthrown to the west; *f*, *f*, *f*, faults. The heavy black band represents the supposed position of the coal beds. North and south of this section the beds appear to be deeply faulted down against the western margin, and the apparent synclinal structure disappears. The superficial portion of this section is based on observation and reliable information; the deeper portion is hypothetical. (*After Shaler and Woodworth, U. S. Geol. Surv., 19th Ann. Rept., Pt. II.*)

Eastern Interior Field (34, 57–59, 65–69). — This field is an oval, elongated basin (Fig. 11), extending northeast and southwest, with the marginal beds dipping gently toward the lowest portion, which lies in Illinois, where the beds are nearly horizontal. It covers most of Illinois, southwestern Indiana, and a small part of Western Kentucky, with some small outliers in Missouri, near St. Louis and St. Charles, and two in Illinois.

The coal-bearing rocks rest unconformably on lower Carboniferous, Devonian, and Silurian strata, the basal member being a sandstone, probably the equivalent of the Pottsville. The entire section of coal-bearing rocks, attaining a thickness of 1200 feet, belongs to the Coal Measures, although the upper part may be of Permian age, and the highest workable coal beds are classed as Freeport or Conemaugh. The coal seams occur in the lower portion of the section, and hence outcrop around the margin, the mining operations being therefore confined to a narrow belt, because near the center of the basin the coal beds underlie too great a thickness of unproductive strata to permit of profitable working under present conditions.

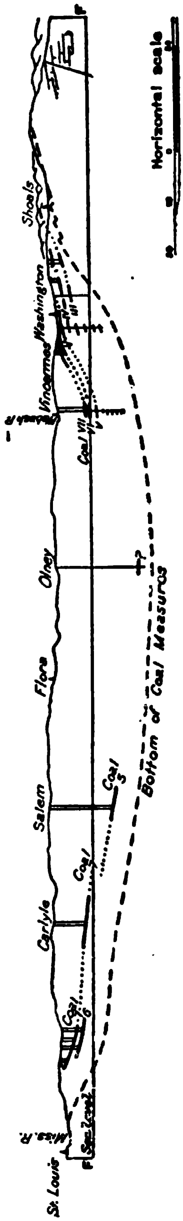

FIG. 11.—Section across Eastern Interior coal field. (*After Ashley, U. S. Geol. Surv., 22d Ann. Rept., III.*)

Great difficulty has been encountered in attempts at correlation of the coal beds of different parts of the field, because of the varying section shown from place to place, and lack of continuity of the beds. In consequence, the custom has arisen of giving the coal beds numbers instead of names.

The coals of the eastern interior field, although varying widely in quality, are all bituminous. On account of their higher percentage of ash and sulphur, they are little used for coking. Most of the coal used in and near this field is supplied from it; but even within the field the Appalachian coals enter into competition. The cannel coal found near Cannelsburg, Kentucky, which is the only good gas producer found in this field, finds a ready market.

In Illinois the section involves (57):—
a. Upper or Barren Coal Measures.
b. Lower or Productive Coal Measures; coal bearing.
c. Millstone Grit or Mansfield Sandstone.

The old survey recognized 16 beds, of which 1–7 are commonly worked, but later work throws doubt on this classification; the areas of important development of the different beds are not coincident, but as a general rule the coals above No. 2 in the western part of the state are persistent in extent and thickness over large areas, while in the eastern portion all the seams are irregular in both extent and thickness. As a rule, the lower seams are better than the upper ones, and the quality also increases from north to south. The Illinois seams vary from 3 to 8 feet in thickness, and all are bituminous.

Ashley subdivides the Indiana section as follows: —

Permian-Merom group; Upper or Barren Measures, 0′–400′.

Coal Measures { Wabash group; main coal-bearing measures, 100′–600′.
Mansfield group; basal sandstone member, 0′–200′.

The coal field is roughly divisible into two areas, viz. an eastern or "block-coal" area, and a western or bituminous area. The former is also bituminous, but shows a peculiar block-like jointing.

Fig. 12. — Shaft house and tipple, bituminous coal mine, Spring Valley, Ill.

The Indiana section shows at least 25 distinct coal beds (59), nearly all of them 2 feet or more thick in some places, and nine of them continuing of minable thickness over large areas. The upper five of the nine numbered ones are coking and occur in broad sheets, while the lower four occur in basins and are not extensively workable. No. 5 is the most important bed in the state and can be correlated the entire length of the field.

In Kentucky the coals have been numbered from 1–12, beginning at the bottom and lettered beginning at the top. Nos. 9, 11, and 12 are the chief ones worked. One of these is exceedingly persistent, being found under a part of the whole of two counties, with an average thickness of 5 feet, and at a depth commonly of less than 200 feet.

Northern Interior Field (72). — This field forms a large basin in which the coal dips irregularly from the margin toward the center (Fig. 13), but on account of the heavy mantle of glacial drift it has been difficult to determine its exact boundaries, and prospecting is necessarily done by means of drilling. The Coal Measures, which are probably of Pottsville age, attain a total thickness of 600 to 700 feet in the center of the basin, and include 7 horizons of workable coal with an average thickness of 2 feet and rarely exceeding 4 feet. The Verne coals near the top may correspond with the Mercer coals of Ohio (Lane). Coal is found near the center of the basin at depths of 400 feet or more, though the beds that are mined are mostly at depths of 100 to 250 feet. All the coals are bituminous and used chiefly for fuel, but some are coking, and others will probably prove of value for gas manufacture. Saginaw and Bay City are important mining towns.

Western Interior Field and Southwestern Fields (35). — These two fields form a practically continuous belt of coal-bearing formations, extending from northern Iowa southwestward for a distance of 880 miles into central Texas. Throughout most of this area the beds lie horizontal, or have a gentle westward dip averaging 10 to 20 feet per mile, but a notable exception is found in the beds of eastern Oklahoma and Arkansas, which are rather strongly folded, reminding one of the Pennsylvania anthracite area.

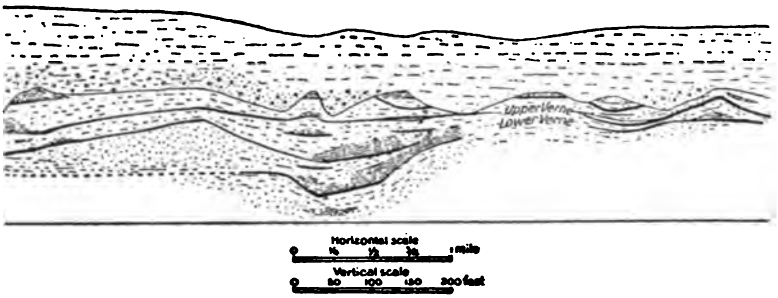

FIG. 13. — Generalized section of Northern Interior coal field. (*After Lane, U. S. Geol. Surv., 22d Ann. Rept., III.*)

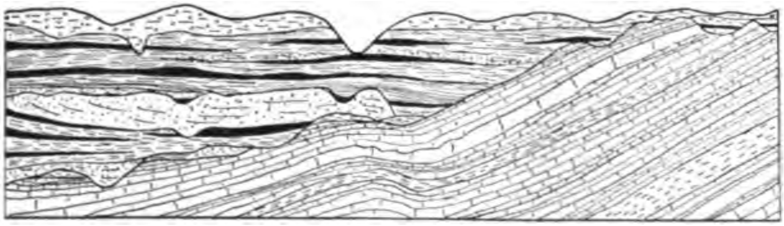

FIG. 14. — Composite section showing structure of lower coal measures of Iowa. (*After Keyes, Ia. Geol. Surv., I.*)

Western Interior Field. — The Coal Measures, composed of limestones, shales, fire clays, and coal beds, rest unconformably on the Mississippian and dip westwardly under beds of Permian, Cretaceous, and Pleistocene. Toward the south and west the beds increase in thickness, the maximum being 1000 feet in Iowa (62), 3000 in Kansas (63), and 200 in Missouri (74). In a general way there is a prevailing dip westward of 10–20 feet per mile; in detail the dip

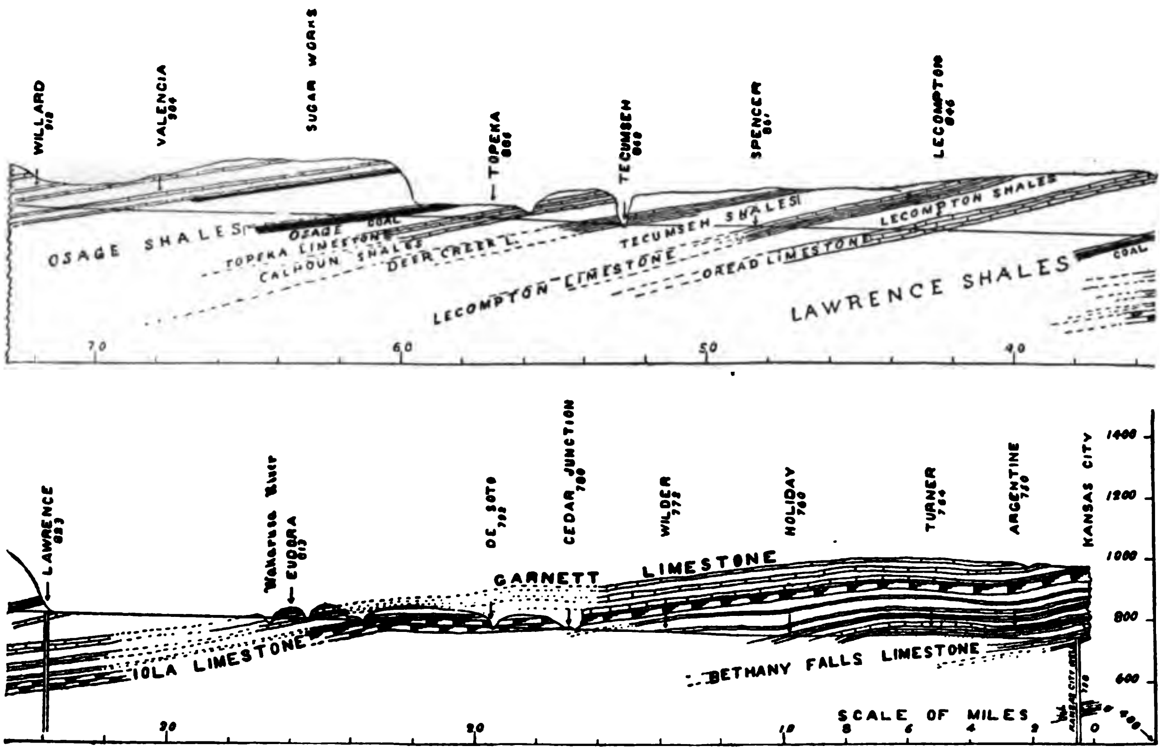

PLATE IV. — Geologic Section from Kansas City to Topeka, Kan. (*Kas. Geol. Surv., III.*)

is south-southwest in Iowa, west-northwest in Missouri, and usually northwest in Kansas.

The Coal Measures are divisible into two parts. The lower is known as the Des Moines in Iowa, and the Cherokee and Marmaton in Kansas. The upper is termed the Missourian in Iowa, but in Kansas is made up of the Pottawatomie, Douglas, and Shawnee. In both states most of the coal mined comes from the Cherokee shales horizon. Those found in the upper measures are thin, even though persistent.

Most of the coal mined in this field comes from the lower part of the coal measures, where the beds are irregular in thickness and distribution, in consequence of deposition on a very uneven surface.

All the coals of this field are essentially bituminous and used chiefly for steaming and heating purposes, being of no value for either coking or gas making. Some of the seams will coke, but there is no demand for the product, and the sulphur and ash are too high for gas making.

The Oklahoma and Arkansas portions of the Western Interior field are directly connected, but the coals differ somewhat.

The rocks of the Oklahoma field (60), belong to the Coal Measures (Fig. 15), the lowest coal beds being probably in the upper part of the Lower Coal Measures, and the highest coal in the Upper Coal Measures.

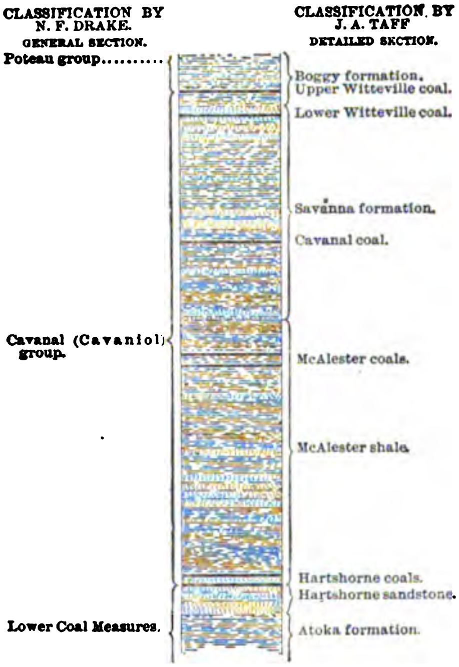

FIG. 15. — Columnar section of coal-bearing rocks in Oklahoma coal field. (*After Taff, U. S. Geol. Surv., 22nd Ann. Rept., Pt. III.*)

The coal field is characterized by both folds and faults. The anticlines are generally narrower and deeper than the synclines, with a tendency to overturn to the north, but the folds die out to the westward and northwestward. There are seven important beds of workable character, as well as some that are workable locally. The coals are bituminous and coking.

In the Arkansas field (49) the rocks (sandstones and shales) are all of Pennsylvanian age, and involve a section several thousand feet thick, which can be correlated fairly well with the Oklahoma area. They are bent into a trough in which there are a number of subordinate folds and some normal and thrust faults. The coals of the Hartshorne horizon (Fig. 16) are economically the most important, while those below it are probably thin and not continuous. The coals range from bituminous to semi-anthracite, and, although not of coking character, excel in quality any found west of West Virginia.

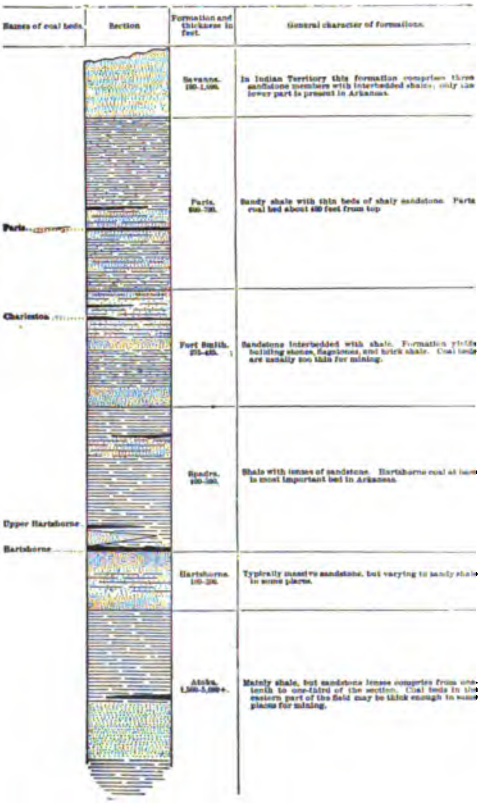
Names of coal beds.
Section
Formation and thickness in feet.
General character of formations.
Savanna.
In Indian Territory this formation comprises three sandstone members with interbedded shales; only the lower part is present in Arkansas.
Paris.
Sandy shale with thin beds of shaly sandstone. Paris coal bed about 400 feet from top
Paris
Charleston
Fort Smith.
Sandstone interbedded with shale. Formation yields building stones, flagstones, and brick shale. Coal beds are usually too thin for mining.
Spadra.
Shale with lenses of sandstone. Hartshorne coal at base is most important bed in Arkansas.
Upper Hartshorne
Hartshorne
Hartshorne.
Typically massive sandstone, but varying to sandy shale in some places.
Atoka.
Mainly shale, but sandstone lenses comprise from one-tenth to one-third of the section. Coal beds in the eastern part of the field may be thick enough in some places for mining.

FIG. 16. — Generalized columnar section of the coal-bearing rocks of Arkansas. (*After Collier, U. S. Geol. Surv., Bull.* 326.)

Southwestern Field (40). — This area, lying in northern Texas, is separable into a northern and southern portion by an arm of Cretaceous strata, extending across it. The coals, which are all Pennsylvanian, rest unconformably on the Mississippian and are overlain by the Permian on the north. There are five divisions, which carry three workable coal beds, and while all are of bituminous character, none of them are coking.

Rocky Mountain Fields (38). — These cover a broad area extending from the Canadian boundary southward into New Mexico,

PLATE V

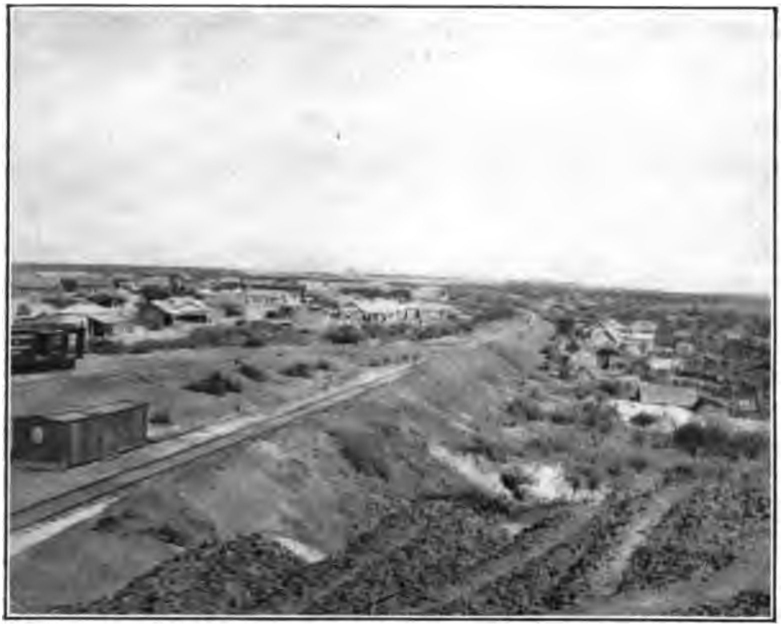

FIG. 1.—View in sub-bituminous coal area, between Minera and Cannel, Texas. (*H. Ries, photo.*)

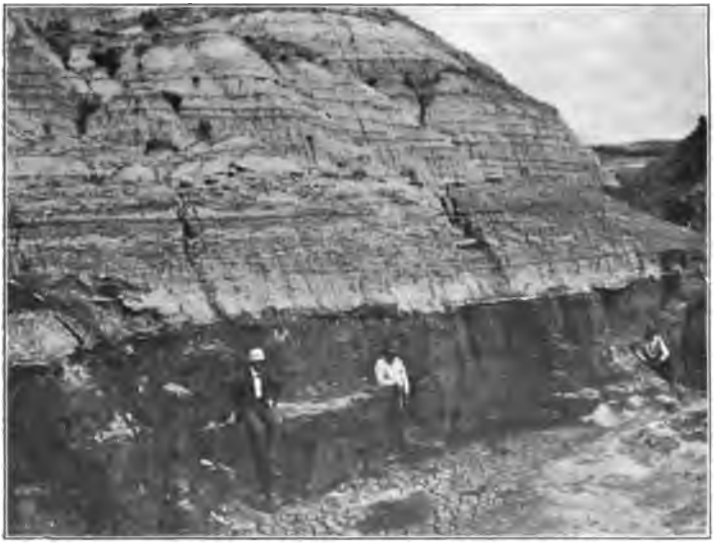

FIG. 2. — Lignite seam, Williston, N. Dak. (*After F. Wilder, photo.*)

a distance of about 1000 miles, and including a large number of fields of varying size and irregular shape. Most of these beds lie within the mountainous region, but at the northern end of the area, in Wyoming and the Dakotas, the coal fields extend eastward under the Great Plains for some distance. The age of the coal ranges from Lower Cretaceous to Eocene (Tertiary), though most of it belongs to the former.

While portions of this enormous area of coal-bearing strata are only slightly disturbed, mountain-building forces and igneous intrusions have affected a large proportion of the region, often materially changing the character of the coal. Thus, while in undisturbed portions of the field the beds may be lignitic (Pl. V, Fig. 2), in the disturbed parts they have been altered to bituminous. Igneous intrusions may have changed the latter locally to anthracite, as in the Crested Butte (55) area of Colorado or the Cerrillos field of New Mexico (80). Some of the bituminous coals produce an excellent quality of coke.

Colorado (54, 55) is the most important coal-producing state (Fig. 17) of the Rocky Mountain region. This is due, not only to the quality of its coals, but also to the presence within the state of extensive metallurgical industries. The Raton field in the southeastern part of the state, extending into New Mexico (82), is at present the most important producer. Like many of the fields of this region the age of the coals in this is Laramie, (Cretaceous), and the beds are both folded and faulted. They are, moreover, crossed by igneous intrusions, which have in some places produced natural coke, but in others destroyed the value of the coal. The coals are bituminous and some are coking. Those of the South Platte field are subbituminous and worked mainly north of Denver; so too are those of the North Park and Yampa fields, but the latter contains some anthracite formed by igneous intrusions. In the San Juan River region, where Upper Cretaceous coals occur, the latter changes from sub-bituminous in the southern part to bituminous on the flanks of the San Juan mountains. The Canyon City field carries bituminous noncoking coal and the Uinta basin bituminous grades.

Wyoming (116–118) has a larger percentage of its area underlain by coal-bearing rocks than any other Rocky Mountain state, but most of this lies in the Great Plains region, and hence the coals, which are mostly Cretaceous, are on the whole of lower quality. The location of the fields is shown in part on the accompanying map. The coals are mainly of subbituminous character, but some are bituminous, as around Rock Springs and in the Hams Fork Region, as well as in part of the Green River and Black Hills fields.

A great area of Eocene lignitic coal is found in the Fort Union Region of North Dakota, South Dakota, and Montana (75–77). Farther west in Montana, in the Great Falls and Lewistown fields of the Judith Basin, bituminous coal, some of it of coking quality, is found. These last two are of Kootenai (Cretaceous) age. Sub-bituminous coals of Upper Cretaceous age are found in the Assiniboine Region of northern Montana.

Utah (109) has two large coal areas. One of these, forming a part of the Uintah region and lying southeast of Salt Lake City, carries Upper Cretaceous coals of bituminous character, which can be coked. The second, in the southwestern part of the state, also supplies bituminous coal.

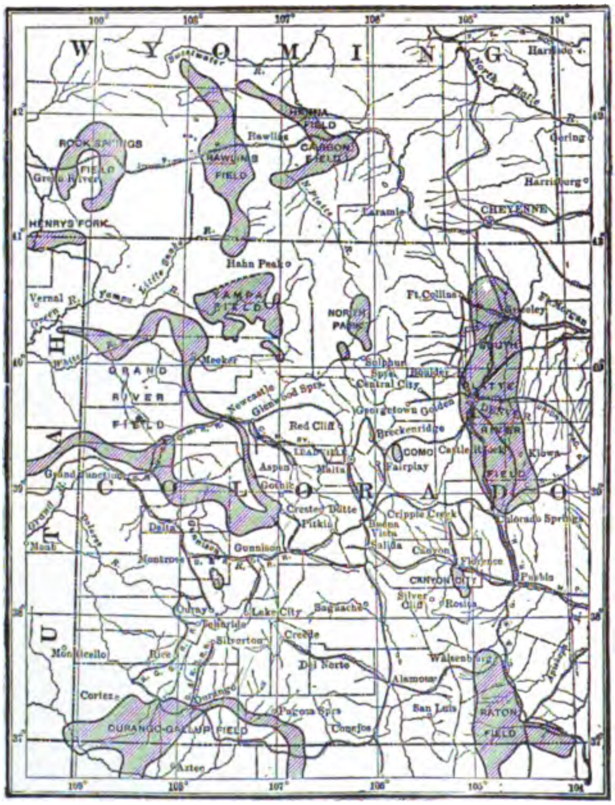

FIG. 17. — Index map of Colorado coal fields. *(After Campbell, U. S. Geol. Surv., Bull. 297.)*

Gulf Province Lignites (70, 73, 105–107). — These are of Eocene (Tertiary) age and are all low grade, with the exception of those along the Rio Grande, northwest of Laredo, which may be regarded as sub-bituminous. Those found near Eagle Pass are of still better quality, but occur in the Cretaceous.

Pacific Coast Fields (37). — Tertiary coals, partly bituminous, though mainly lignitic, occur scattered over a wide area in the states of California (50–53), Washington (114), and Oregon (93, 94). The separate fields are limited in extent, and widely separated. Their output is small as compared with some other states, but still it is becoming of growing importance.

Of the scattered fields in Washington, the most important lie directly east of Seattle and Tacoma. The total thickness of coal-bearing strata is about 10,000 feet, but important coal beds are found only in the lower 2000 feet. The quality of the coal varies with the extent of the dynamic disturbance, and hence there may be variation even in a single field, and, in fact, in a single mine. California is an important market, even though the coal has to compete with fuel oils.

Both California and Oregon are small producers. In the former coals of subbituminous character have been mined near Tesla, Alameda County, and recently coal of good bituminous grade has been worked in Stone Canyon, Monterey County. Indeed this is of sufficiently high quality to compete with foreign coals brought into San Francisco.

In Oregon, the Coos Bay field has been a small but fairly steady producer.

The coal trade conditions of the Pacific coast have been unique. The local supply is not equal to the demand, and the Rocky Mountain fields are too far off to supply the Pacific coast with cheap fuel. Therefore, much coal is imported, bringing about a competition in San Francisco from other countries, including England, Wales, Scotland, Australia, Japan, and British Columbia. These foreign coals are often of better grade than the Pacific

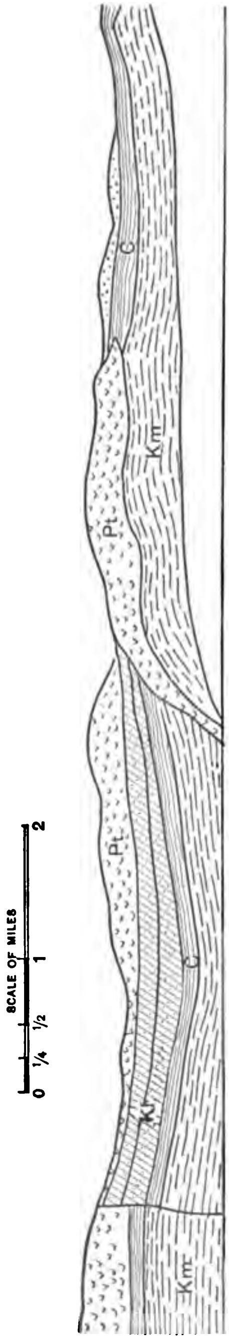

FIG. 18. — Geologic section (northwest-southeast) in southeastern part of Anthracite Colo. sheet. Kl, Laramie (Cretaceous) sandstone; Km, Montana (Cretaceous) sandstone and shale; Pt, porphyrite; C, coal-bearing beds. (*U. S. Geol. Surv.*)

coast coals, and they can be imported with low freight rate as ballast in wheat-carrying vessels that come to San Francisco for cargoes. These coal imports form three-quarters of the total import coal tonnage of the United States; but since 1895 there has been a steady decrease in the importation of coal and an increase in the Pacific coast production.

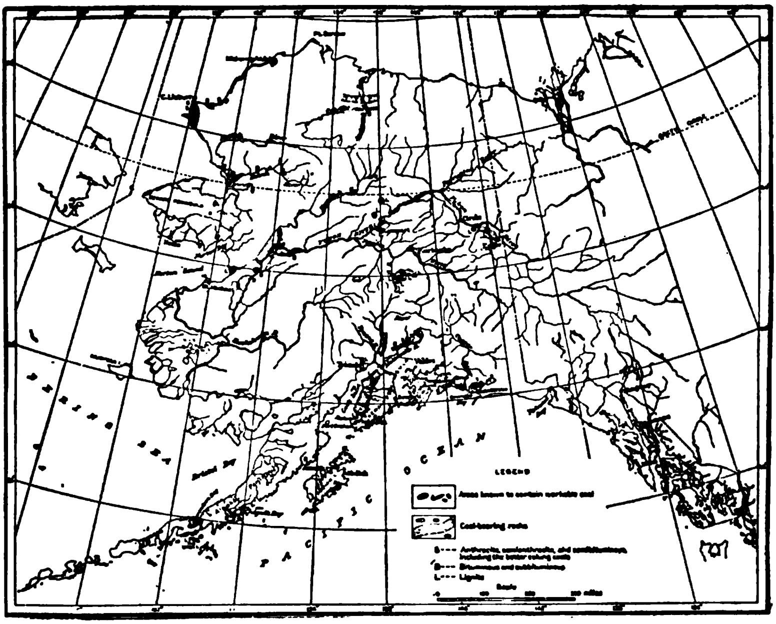

FIG. 19. — Map of Alaska, showing distribution of coal and coal-bearing rocks, so far as known. (*After Martin, U. S. Geol. Surv., Bull.* 314.)

Alaska (45, 46). — Although Alaskan coal was first mined in 1852 at Port Graham, the resources of the region are still but little known to most people, and only slightly developed. The explorations for gold during the last few years, together with the field work done by the United States Geological Survey, have proved that coal is widely distributed in the Alaskan territory (Fig. 19). The deposits range geologically from the Carboniferous to the Tertiary, those of the latter age being the most abundant.

Lack of knowledge regarding the better coals and insufficient transportation facilities are among the causes that have retarded the development of the coal fields.

In the Pacific coast region fields of Mesozoic and Tertiary coals, ranging from lignite to anthracite, are known at several points, and while many of the beds are of great thickness, the irregularity of the structure produces unfavorable mining conditions. However, these coals are well located for shipment.

The interior region, including the Copper and Yukon River valleys and their tributaries, carries Cretaceous bituminous coal on the lower Yukon and Tertiary lignite and sub-bituminous coal on the upper Yukon as well as in the Tanana, Koyukuk, and Copper River basins. This coal can only become of local importance.

In the Bering Sea and Arctic slope region coals of Carboniferous, Jurassic, Cretaceous, and Tertiary age are present. None of these are likely to become of immediate value, except for local use, although the high-grade coal of Cape Lisburne may prove an important source of supply for Nome; but still the shipping problem is a serious one.

Production of Coal. — The first mention of coal in the United States is probably in the journal of Father Hennepin, who in 1679 recorded the site of a " cole mine " on the Illinois River near the present city of Ottawa, Illinois, but the first actual mining appears to have occurred in the Richmond basin, Virginia, about seventy years later. The first records of production are in 1822. Ohio probably ranks second in priority of production, as coal was discovered there in 1755, but the records of mining date only to 1838. The mining of Pennsylvania anthracite began in 1790, and in 1807, 55 tons were shipped to Columbus, Ohio. The regular production dates from 1814.[1]

The phenomenal growth of the coal mining industry is well shown by the diagram (Fig. 20).

The production of the individual states since 1904 is given on page 39.

Grouping the output by regions, the overwhelming importance of the Appalachian region is well seen.

PRODUCTION OF COAL IN UNITED STATES BY REGIONS FROM 1904 TO 1908, IN SHORT TONS

REGION	1904	1905	1906	1907	1908[2]
Anthracite (Pa., Colo., N. Mex.)	73,228,773	77,734,673	71,342,659	85,666,404	83,310,412
Triassic	9,100	1,557	—	—	—
Appalachian	182,606,561	212,633,324	233,473,524	266,501,527	216,499,163
Northern	1,342,840	1,473,211	1,346,338	2,035,858	1,835,019
Eastern	51,682,313	55,255,541	59,457,660	71,598,256	65,774,700
Western and Southwestern	23,273,482	23,265,750	23,086,348	26,856,622	23,645,983
Rocky Mountain, etc	16,344,516	19,303,188	22,064,003	23,929,155	21,644,307
Pacific coast and Alaska	3,328,803	3,055,391	3,386,746	3,775,602	3,133,064

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[1] Parker, E. W., Min. Res. U. S. Geol. Surv., 1908.

[2] The falling off in 1908 was due to business depression.

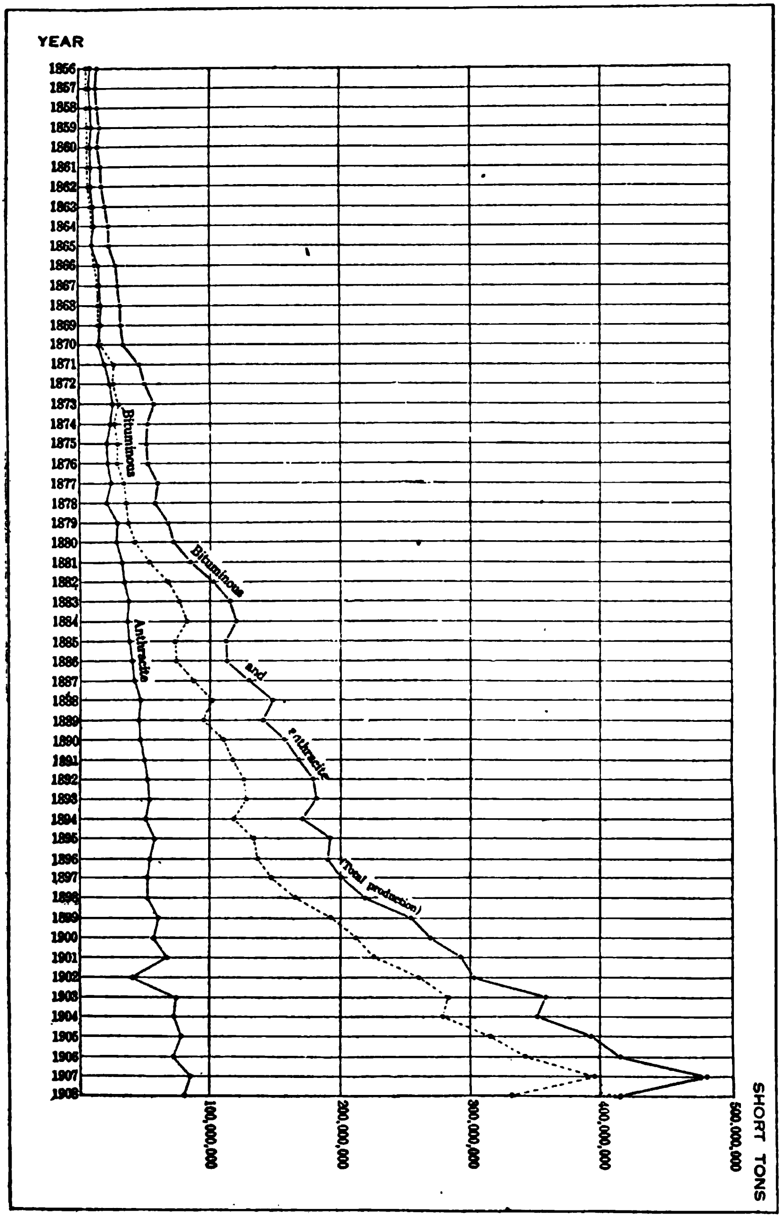

FIG. 20. — Yearly production of anthracite and bituminous coal from 1856 to 1908, in short tons. (*After Parker, U. S. Geol. Surv., Min. Res. for* 1908.)

QUANTITY AND VALUE OF COAL PRODUCED IN THE UNITED STATES, 1904–1908, IN SHORT TONS

STATE OR TERRITORY	1904		1905		1906		1907		1908	
	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE
Alabama	11,262,046	$13,480,111	11,866,069	$14,387,721	13,107,963	$17,514,786	14,250,454	$18,405.468	11,604,593	$14,647,891
Arkansas	2,009,451	3,102,660	1,934,673	2,880,738	1,864,268	3,000,339	2,670,438	4,473,693	2,078,357	3,499,470
California and Alaska	79,582	377,306	80,824	395,975	30,831	78,684	24,089	91,813	21,862	69,650
Colorado	6,658,355	8,751,821	8,826,429	10,810,978	10,111,218	12,735,616	10,790,236	15,079,449	9,634,973	13,586,988
Georgia and North Carolina	390,191	476,996	353,548	456,184	[2] 332,107	[2] 424,004	[2] 362,401	[2] 499,686	264,822	364,279
Idaho	3,480	13,730	[1] 5,882	[1] 17,846	[3] 6,165	[3] 24,238	[4] 7,588	[4] 31,119	5,429	21,832
Illinois	36,475,060	39,941,993	38,434,363	40,577,592	41,480,104	44,763,062	51,317,146	54,687,382	47,659,690	49,978,247
Indiana	10,842,189	12,004,300	11,895,252	12,492,255	12,092,560	13,116,261	13,985,713	15,114,300	12,314,890	13,084,297
Indian Territory or Oklahoma	3,046,539	5,532,066	2,924,427	5,145,358	2,860,200	5,482,366	3,642,658	7,433,914	2,948,116	5,976,504
Iowa	6,519,933	10,504,406	6,798,609	10,586,381	7,266,224	11,619,455	7,574,322	12,258,012	7,161,310	11,906,402
Kansas	6,333,307	9,640,771	6,423,979	9,350,542	6,024,775	8,979,553	7,322,449	11,159,698	6,245,508	9,292,222
Kentucky	7,576,482	7,868,192	8,432,523	8,385,232	9,653,647	9,809,938	10,753,124	11,405,038	10,246,553	10,317,162
Maryland	4,813,622	5,729,085	5,108,539	5,831,760	5,435,453	6,474,793	5,532,628	6,623,697	4,377,093	5,116,753
Massachusetts	—	—	—	—	—	—	—	—	50	150
Michigan	1,342,840	2,424,935	1,473,211	2,512,697	1,346,338	2,427,404	2,035,858	3,660,833	1,835,019	3,322,904
Missouri	4,168,308	6,801,751	3,983,378	6,291,661	3,758,008	6,118,733	3,997,936	6,540,709	3,317,315	5,444,907
Montana	1,358,919	2,194,548	1,643,832	2,823,350	1,829,921	3,240,357	2,016,857	3,907,082	1,920,190	3,771,248
New Mexico	1,452,325	1,904,499	1,649,933	2,190,231	1,964,713	2,638,986	2,628,959	3,832,128	2,467,937	3,368,753
North Dakota	271,928	389,052	317,542	424,778	305,689	451,382	347,760	560,199	320,742	522,116
Ohio	24,400,220	26,579,738	25,552,950	26,486,740	27,731,640	30,346,580	32,142,419	35,324,746	26,270,639	27,897,704
Oregon	111,540	243,588	109,641	282,495	79,731	212,338	70,981	166,304	86,259	236,021
Pennsylvania bituminous	97,938,287	94,428,219	118,413,637	113,390,507	129,293,206	130,290,651	150,143,177	155,664,026	117,179,527	118,816,303
Tennessee	4,782,211	5,642,393	5,766,690	6,577,881	6,259,275	7,667,415	6,810,243	8,490,334	6,199,171	7,118,499
Texas	1,195,944	1,983,636	1,200,684	1,968,558	1,312,873	2,178,901	1,648,069	2,778,811	1,895,377	3,419,481
Utah	1,493,027	1,943,440	1,332,372	1,793,510	1,772,551	2,408,381	1,947,607	2,959,769	1,846,792	3,119,338
Virginia	3,410,914	2,921,911	4,275,271	3,777,325	4,254,879	4,183,991	4,710,895	4,807,533	4,259,042	3,868,524
Washington	3,137,681	5,120,931	2,864,926	5,141,258	3,276,184	5,908,434	3,680,532	7,679,801	3,024,943	6,690,412
West Virginia	32,406,752	28,647,014	37,791,580	32,341,790	43,290,350	41,051,939	48,091,583	47,846,630	41,897,843	40,009,054
Wyoming	5,178,556	6,747,909	5,602,021	7,336,951	6,133,994	8,013,528	6,252,990	9,732,668	5,489,902	8,868,157
Total bituminous	278,659,689	305,397,001	315,062,785	334,658,294	342,874,867	381,162,115	394,759,112	451,214,842	332,573,944	374,135,268
Pennsylvania anthracite	73,156,709	138,974,020	77,659,850	141,879,000	71,282,411	131,917,694	85,604,312	163,584,056	83,268,754	158,178,849
Grand total	351,816,398	444,371,021	392,722,635	476,537,294	414,157,278	513,079,809	480,363,424	614,798,898	405,842,698	532,314,117

[1] Includes production of Nevada.
[2] Georgia only.
[3] Includes production of Nevada.
[4] Includes production of Nebraska and Nevada.

Price per Ton. — The average price per short ton of coal fluctuates somewhat from year to year, and yet not as much as one might imagine. The figures below show the prices for the last ten years.

Average Price per Short Ton of Coal in the United States since 1898

Year	Anthracite	Bituminous	Year	Anthracite	Bituminous
1898	$1.41	$0.80	1904	$1.90	$1.10
1899	1.46	.87	1905	1.83	1.06
1900	1.49	1.04	1906	1.85	1.11
1901	1.67	1.05	1907	1.91	1.14
1902	1.84	1.12	1908	1.90	1.12
1903	2.04	1.24			

Exports and Imports. — The exports consist of anthracite and bituminous coal, the quantity of bituminous being the greater in the last few years. They are made principally by rail over the international bridges and by lake and sea to the Canadian provinces. Exports are also made by sea to the West Indies, to Central and South America, and elsewhere.

The imports are principally from Australia and British Columbia to San Francisco, from Great Britain to the Atlantic and Pacific coasts, and from Nova Scotia to Atlantic coast points.

The statistics since 1904 are given below: —

Coal of Domestic Production exported from the United States, 1904–1908, in Long Tons

Year	Anthracite		Bituminous and Shale	
	Quantity	Value	Quantity	Value
1904	2,228,392	$11,077,470	6,345,126	$17,160,538
1905	2,229,983	11,104,654	6,959,265	17,867,964
1906	2,216,969	10,896,200	7,704,850	19,787,459
1907	2,698,072	13,217,985	10,448,676	26,972,908
1908	2,752,358	13,524,595	9,100,819	23,361,914

Coal imported and entered for Consumption in the United States, 1904–1908, in Long Tons

Year	Anthracite		Bituminous and Shale	
	Quantity	Value	Quantity	Value
1904	72,529	$220,664	[1] 1,550,751	$3,895,469
1905	34,241	107,314	[1] 1,611,002	3,903,765
1906	32,354	105,161	[1] 1,702,799	4,102,355
1907	9,897	40,971	2,103,711	5,397,222
1908	16,484	73,778	1,452,662	3,964,843

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[1] Includes 579,204 tons of slack or culm passing ¼-inch screen imported in 1904, 611,053 tons imported in 1905, and 659,486 tons imported in 1906.

World's Production. — The following figures are those given by the U. S. Geol. Survey, and compiled from various sources: —

COUNTRY		USUAL UNIT IN PRODUCING COUNTRY	EQUIVALENT IN SHORT TONS
United States (1908)	long tons	371,288,123	415,842,698
Great Britain (1908)	do.	261,506,379	292,887,144
Germany (1908)	metric tons	215,283,474	237,306,973
Austria-Hungary (1907)	do.	48,180,849	53,109,750
France (1908)	do.	37,622,556	41,471,343
Russia and Finland (1907)	do.	26,023,344	28,685,532
Belgium (1908)	do.	22,679,300	24,999,392
Japan (1907)	do.	13,935,952	15,361,600
India (1908)	long tons	12,769,635	14,301,991
Canada (1908)	short tons	10,904,466	10,904,466
New South Wales (1908)	long tons	9,147,025	10,244,668
Spain (1907)	metric tons	3,887,236	4,284,900
Transvaal (1908)	long tons	3,012,692	3,374,215
New Zealand (1907)	do.	1,831,009	2,050,730
Natal (1907)	do.	1,530,043	1,713,648
Queensland and Victoria (1907)	do.	964,229	1,079,936
Mexico (1906)	metric tons	767,864	846,416
Holland (1906)	do.	532,780	587,283
Italy (1907)	do.	453,137	499,493
Sweden (1907)	do.	305,338	336,574
Cape Colony (1907)	long tons	128,607	144,040
Tasmania (1908)	do.	61,068	68,396
Other countries[1]	do.	7,000,000	7,840,000
Total		——	1,167,941,188
Percentage of the United States		——	35.6

QUANTITY (SHORT TONS) AND VALUE OF COKE PRODUCED IN UNITED STATES FROM 1906 TO 1908

	1906		1907		1908		
STATE	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE	PER CENT YIELD OF COKE FROM COAL
Alabama	3,034,501	$8,477,899	3,021,794	$9,216,194	2,362,666	$7,169,901	61
Colorado and Utah	1,455,905	4,504,748	1,421,579	4,747,436	982,291	3,238,888	63.5
Georgia	70,280	277,921	74,934	315,371	39,422	137,524	55.2
Illinois	268,693	1,205,462	372,697	1,737,464	362,182	1,538,952	72.0
Kansas	1,698	4,101	6,274	19,837	2,497	8,011	65.9
Kentucky	74,064	169,846	[2]	[2]	[2]	[2]	
Montana	38,182	266,024	[2]	[2]	[2]	[2]	
New Mexico	147,747	422,712	265,125	840,253	274,565	826,780	60.4
Ohio	293,994	1,013,248	270,634	819,262	159,578	491,982	67.2
Oklahoma	49,782	204,205	[2]	[2]	[2]	[2]	
Pennsylvania	23,060,511	54,184,531	26,513,214	67,638,024	15,511,634	32,569,621	66.8
Tennessee	483,428	1,350,856	467,499	1,592,225	214,528	561,789	54.2
Virginia	1,577,659	3,611,659	1,545,280	3,765,733	1,162,051	2,121,980	65.1
Washington	45,642	226,977	52,028	293,019	38,889	213,138	57.1
West Virginia	3,713,514	8,192,956	4,112,896	9,717,130	2,637,123	5,267,054	63.9
Other states	2,085,617	7,474,889	2,655,610	10,837,178	2,286,092	8,338,363	72.5

[1] Includes China, Turkey, Servia, Portugal, United States of Colombia, Chile, Borneo, and Labuan, Peru, Greece, etc.

[2] Included under other states.

The quantity of coal consumed in manufacture of coke in 1907 was $72,784,851, while the value of the coke was $111,539,126. The production of 1908 was less on account of the financial depression.

There were, in 1908, 551 establishments, operating 101,218 ovens. Of these about 3600 were by-product ovens, from which the average yield of coke is higher (73.6 per cent in 1908). The by-products saved from these were as follows for 1907 and 1908: —

VALUE OF PRODUCTS OBTAINED IN MANUFACTURE OF COKE IN RETORT OVENS IN 1907 AND 1908

	1907		1908	
	QUANTITY	VALUE	QUANTITY	VALUE
Gas . . . . M cubic feet	20,516,731	$3,130,839	16,205,925	$2,557,482
Tar . . . . gallons	53,995,795	1,242,530	42,720,609	1,007,613
Ammonia, sulphate or reduced to equivalent in sulphate . . . pounds	125,372,360	3,174,702	43,329,426	1,286,224
Anhydrous ammonia	——	——	15,445,030	2,530,979
Total value of by-products	——	7,548,071	——	7,382,299
Coke . . . . short tons	5,607,899	21,665,157	4,201,226	14,465,429
Grand total	——	29,213,228	——	21,847,728

Many of these by-product ovens are located in states producing no coal.

PEAT

Origin. — So much attention has been attracted to this material in the last few years that it seems desirable to treat it as a separate topic, and partly so because it can be used for other purposes than fuel.

Peat (128) may be defined as "vegetable matter in a partly decomposed and more or less disintegrated condition," and represents much of the "dark-colored or nearly black soil found in bogs and swamps."[1] The dry peat may be very fibrous and light colored, or compact, structureless, and dark brown or black. If wet, it contains as much as 80 to 91 per cent or even more water. As previously mentioned (p. 3) it is produced by the slow decay, under water, of accumulated plant remains.

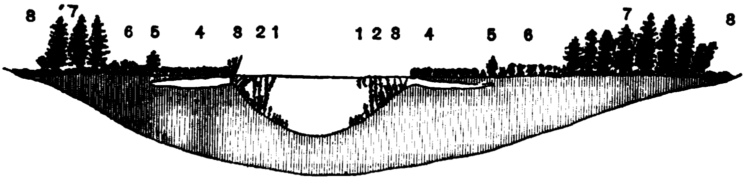

FIG. 21. — Diagram showing how plants fill depressions from the sides and top, to form a peat deposit. — 1. Zone of Chara and floating aquatics. 2. Zone of Potamogetons. 3. Zone of water lilies. 4. Floating sedge mat. 5. Advance plants of conifers and shrubs. 6. Shrub and Sphagnum zone. 7. Zone of Tamarack and Spruce. 8. Marginal Fosse. *(After Davis, Mich. Geol. Surv., Ann. Rept. for 1906.)*

The two essential conditions for peat formation are (1) restricted access of air to impede growth of decay-producing organisms, and (2) abundance of water to permit profuse plant growth.

This decay is accomplished mainly through the agency of fungi and air-requiring bacteria which break down the tissues, the decay involving decrease in bulk, darkening in color, and liberation of gaseous constituents. Both moisture and air are essentials to this process.

Since an abundance of water is essential to peat formation, and as it is formed by accumulation of plants in the spot where they grew, it requires plants of a water-loving nature. But peat may form in lakes or ponds, or in moist depressions or flat areas, and hence plants adapted to these different sets of conditions being different, it follows that the product may come from more than one kind.

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[1] If this material contains too much mineral matter to burn freely, it is technically known as muck.

Peat may be formed in lakes or similar depressions by aquatic plants, including minute algæ, building up a deposit from the bottom and around the sides, in water shallower than 15 feet. The extension of this deposit into deeper water and building up of the bottom permits growth of aquatic seed plants, resulting in establishment of characteristic zones. These are characterized (127) by (1) the pond weeds, *Potamogeton*, next to the deepest water; (2) shoreward of this the pond lilies; (3) the lake bulrush, *Scirpus;* and (4) the amphibious sedges, especially the turf-forming slender sedge. In some localities some of the zones may be absent. The sedges may also extend outward from the shore, forming a floating mat, which may cover the entire surface of the pond, and become covered by a growth of shrubs and even large trees, although the mat may not be more than 4 or 5 feet thick.

Peat may also form on moist, flat, or sloping surfaces, in depressions from which standing water is naturally absent, provided the plant remains are kept saturated with water, which they hold there partly by capillarity. In such situation plants of the rush, grass, sedge type, or *sphagnum* are important. This type of peat accumulation flourishes best in regions of heavy rainfall and moist atmosphere, and the deposit shows an irregularly stratified structure, but more uniform character than the filled-basin type first described, whose structure is more uniform below the original water level, but whose upper 3–5 feet is nearly always of different structure and composition from that below. Some bogs may be of composite origin.

The present surface vegetation of the bog does not necessarily indicate the kind of plant from which the peat was formed.

An interesting type of peat is that found in salt marshes, of which there are thousands of acres along the Atlantic coast, these marshes being poorly-drained plains subject to frequent overflow by the sea-water. Studies by Davis of the Maine marshes (128) indicate that the peat is either of "fresh-water origin below a relatively thin stratum of salt-water peat, or else made up entirely of plants similar to those growing on the marshes to-day at about high tide level." The suggested explanation is that the fresh-water peat has been formed in fresh-water bogs situated on a slowly sinking coast, while the upper or salt-water peat formed when the land was low enough to permit an influx of salt water, thus permitting the growth of only such plants as could stand it.

The fresh-water peat may be of fuel value, but that formed wholly by the growth of salt-marsh plants is too full of fine silt and mud tidal deposits to be of marketable character. (See analyses, p. 6.)

Uses of Peat (119, 126, 127). — The main use of peat is for fuel, but it has never been extensively used in America for this purpose. A number of experimental plants have been built in Canada, but most of them have not been successful nor have any been so in the United States. The failure may have been due to lack of capital, improper machinery, or lack of experience. Since a detailed discussion of peat-fuel technology is beyond the limits of this work, those wishing to follow it up are referred to Nos. 126, 127, 128, of the bibliography.

For fuel purposes the peat may be used in air-dried form [illegible] comes from the bog, pressed into blocks (machine peat), in briquettes with or without binder, or in gas producers. Peat charcoal and peat coke are manufactured in considerable and increasing quantities in Germany and Russia for use in metallurgical work, but the by-product gases are saved in connection with the coking process.

Of importance is the use of the more fibrous kinds of peat as a material for bedding for stock and for packing, as well as for deodorizing and disinfecting. Those varieties of powdered peat which are rich in nitrogen are dried and sold for filler in certain kinds of artificial fertilizer, and although a use of recent origin it seems to be growing. "Mull" is the finer matter separated from moss litter by screening, and sold for deodorizing, filtering, disinfecting, and packing purposes. It is manufactured at Garrett, Indiana.

The manufacture of fertilizer filler is at present the largest industry based on peat in the United States.

Those peats having a strong fiber can be used in the manufacture of cloth and paper, but the American material is unsuited to this purpose. Peat can also be utilized for making ethyl alcohol, and also for pressing into a structural material resembling wood.

Distribution in the United States. — Those regions possessing peat beds of sufficient size and depth to be of commercial value, lie mostly outside of the coal-producing territory.

Davis states that workable beds are found in many states lying north of the Ohio and east of the Missouri rivers, in the coastal portions of the Middle and South Atlantic and Gulf states, and in the narrow strip along the Pacific coast from southern California northward to the Canadian boundary.

Production of Peat. — Few statistics showing the production of peat in the United States are available. The United States Geological Survey report gives the total production of peat fertilizer filler in 1908 as 23,000 tons, averaging $5.25 per ton at the plant. Five peat fuel plants were operated in a small way during the year. Peat moss litter was manufactured at Garrett, Indiana, the material being sold in bales of 225 pounds, valued at $1.25 per bale. The production was 8000 bales.

The imports of peat moss for the last three years were as follows:

YEAR	QUANTITY	VALUE
	Long Tons	
1906	7,640	$45,344
[illegible]	7,950	46,881
[illegible]08	8,102	45,414

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CHAPTER II

PETROLEUM, NATURAL GAS, AND OTHER HYDROCARBONS

Introductory. — Under this head are included four well-known substances, viz. natural gas, petroleum, mineral tar or maltha, and asphaltum, all essentially compounds of carbon and hydrogen — hydrocarbons — or mixtures of such compounds. In addition they may contain many impurities, such as sulphur compounds, oxidized and nitrogenous substances, etc., whose exact nature may be doubtful.

The hydrocarbons are divisible primarily into a number of regular series, each of which has a generalized formula as indicated below.

1. C_nH_{2n+2}
2. C_nH_{2n}
3. C_nH_{2n-2}
4. C_nH_{2n-4}
5. C_nH_{2n-6}
6. C_nH_{2n-8}
7. C_nH_{2n-10}
8. C_nH_{2n-12}

18. C_nH_{2n-32}

Members of the first eight series have been discovered in petroleum. Of the above formulas, the first represents the paraffin hydrocarbons, beginning with marsh gas or methane, CH_4, and ranging at least as high as the compound $C_{35}H_{72}$. Methane is gaseous, the middle members of the series are liquids, while the higher members are solids, like ordinary paraffin. Members of the second series are also important in petroleums, especially the olefine subseries. The third or acetylene series is represented in some petroleums by its higher members. The fifth or benzine series occurs in nearly all petroleums, but not in large amounts.

Properties of Petroleum (4, 10, 12). — Crude petroleum is a liquid of complex composition and variable color and density. It consists of a mixture of hydrocarbons, mainly liquid, with some gaseous and solid ones, the last being in solution. The American petroleum may have either a paraffin base (most Pennsylvania oils), an asphaltic base (Texas), or a mixed asphaltic and paraffin base (some Illinois petroleums). It is probably safe to say that the paraffin oils predominate east of the Mississippi, while the asphaltic oils are more abundant west of it.[1]

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[1] For a résumé of the different hydrocarbons discovered in American and Canadian oils, see F. W. Clarke, U. S. Geol. Surv., Bull. 330.

Most petroleum contains some nitrogen, but it rarely exceeds 2 per cent, except in some California oils, where it may reach 10 or 20 per cent.[1]

Sulphur is rarely absent, but the quantity found is usually quite small. The Lima, Ohio, and Texas oils carry it in sufficient quantity to require its elimination in refining.

The following are analyses of several petroleums from American and foreign localities: —

ELEMENTARY ANALYSES OF PETROLEUM

	Per Cent			Specific Gravity $H_2O = 1$
	C	H	O	
Heavy oil, W. Va.	83.5	13.3	3.2	.873
Light oil, W. Va.	84.3	14.1	1.6	.8412
Heavy oil, Pa.	84.9	13.7	1.04	.886
Light oil, Pa.	82.0	14.8	3.2	.816
Parma, Italy	84.0	13.4	1.8	.786
Hanover, Germany	80.4	12.7	6.9	.892
Galicia, Austria	82.2	12.1	5.7	.870
Light oil, Baku, Rus.	86.3	13.6	0.1	.884
Heavy oil, Baku, Rus.	86.6	12.3	1.1	.938
Java	87.1	12.0	0.9	.923
Beaumont, Texas	86.8	13.2	—	.920

Petroleums commonly vary in specific gravity between about .8 and .98, the following being some of the limits shown by American oils: —

SPECIFIC GRAVITY OF SOME AMERICAN PETROLEUMS

State	Specific Gravity	Gravity Beaumé[2]
California (Placerita Cañon)	.777 +	50 +
Pennsylvania	.801–.817	46.2–42.6
Ohio	.816–.860	42.8–32.5
Kansas	.835–1.000	38.8–10.0
West Virginia	.841–.873	37.6–30.0
Beaumont, Texas	.904–.925	24.8–31.1
Wyoming	.912–.945	23.3–11.9
California	.920–.983	21.9–12.3

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[1] Jour. Soc. Chem. Ind., XIX : 505, 1900.

[2] A specific gravity of 1, compared with water, is 10° on the Beaumé scale. Conversion from one scale to the other may be made by following formula: —

$$\text{Beaumé} = \frac{140}{\text{Sp. Gr.}} - 130; \text{ or Sp. gr.} = \frac{140}{130 + \text{Beaumé}}.$$

The temperature at which crude petroleum solidifies ranges from 82° F. in some Burma oils to several degrees below zero in certain Italian oils. The flashing point, or the lowest temperature at which inflammable vapors are given off, may be as low as zero degrees in the Italian oils to as high as 370° F. in an oil found on the Gold Coast of Africa, but these are extreme limits. There is also a great range in the boiling point, which is 180° F. in some Pennsylvania oils and 338° F. in oils found at Hanover, Germany.

The various liquid hydrocarbons making up crude petroleum vary in their specific gravity and boiling point. The more important oils which can be separated from crude petroleum by distillation are gasoline, benzine, heavy naphthas, and residuum. Those with a paraffin base are generally lighter and more valuable on account of the higher quantity and quality of the naphthas, illuminating oils, and lubricating oils which they produce. Those with an asphalt base are of inferior quality and chiefly valuable for fuel. Their transportation by pipe lines is also more difficult.

The percentage of the different distillates varies.

The following average percentages of distillates were yielded by the oils of several fields in 1902 (Oliphant): —

	Appalachian Field	Lima, Ind., Field	Kansas Field
Naphthas	20.1	10.9	18
Illuminating oils	61.4	48.8	30
Lubricating and heavy oils	7.1	17.2	25
Residuum	6.3	—	—
Loss from uncondensed products and water	5.1	23.0	27

In the following table (p. 53) there are given a number of determinations of distillates, etc., published by Dr. David T. Day, of the United States Geological Survey, and in part made by him.

Properties of Natural Gas. — This consists chiefly of marsh gas — fire damp — CH_4. It is colorless, odorless, burns readily with a luminous flame, and when mixed with air it is highly explosive.

Ethane (C_2H_4), the next member of the marsh gas series, may exist in considerable quantities in natural gas. Ethylene, or olefiant gas (C_2H_6), burns with a much more luminous flame than the two preceding, but it rarely exists in American gas in amounts greater than a small fraction of one per cent. Carbon monoxide occurs only in very small quantities, and the same is true of carbon dioxide. Nitrogen is found in variable amounts, and oxygen is not uncommon, but when present in large quantity in an analysis, it may be due to contamination of the sample analyzed with air.

LOCATION OF WELL	DEPTH OF WELL (FEET)	LOCATION OF POOL	PHYSICAL PROPERTIES			DISTILLATION BY ENGLER'S METHOD 100 CC. AT 60° F. TAKEN								UNSATURATED HYDROCARBONS		PARAFFIN (PER CENT)	ASPHALT (PER CENT)
			GRAVITY AT 60° F.		COLOR	BEGINS TO BOIL AT (° C.)	BY VOLUME										
							To 150° C.		150° TO 300° C.		RESIDUUM		TOTAL (CUBIC CENTIMETERS)				
			Specific	Degrees Baumé			Cubic Centimeters	Specific Gravity	Cubic Centimeters	Specific Gravity	Cubic Centimeters	Specific Gravity		Crude (per cent)	150° to 300° (per cent)		
Katalla Bay., Alas.[1]			.828	39.5			21.0	.7573	51.0	.8204	28.0						
Oil Bay, Alas.[2]			.9557	16.5	Dark Green	230° C.			13.2	.8777	86.8						
Contra Costa, Fresno County, Cal.[3]			.9667	14.8	Black		3.7		[1]54.5		42.8						21.0
Fresno County, Coalinga, Cal.[4]			.7609	54		49° C.	[1]30.0		[2]60.0		10.0						10.0
Oil City, Coalinga, Cal.[5]			.8584	33.1			28.0		[1]50.0		22.0						
Kern County, Kern River, Cal.[6]	1052		.9609	15.7			0		20.2	.8626	79 8						21.4
McKittrick, Cal.[7]			.9480	17.7	Black		0		[1]39.9		60.1						14.25
Sunset, Cal.[8]			1.00	9.9					[1]5.0		95.0						51.0
East End Field, Los Angeles City, Cal.[9]	1275		.9774	13.2			0		12.0	.8912	88.0						19.8
Newhall Dist., Cal.[10]	750		.8758	29.9			20.3	.7686	34.1	.8424	45.6						10.9
Puente Dist., Cal.[11]	1425		.8775	29.5			23.4	.7564	33.1	.8442	43.5						13.1
Santa Barbara, County Lompoc, Cal.[12]	2500		.9574	16.2			5.2		31.5	.8417	63.3						20.6
Santa Maria field, Cal.[13]	1600		.8882	27.6			25.9	.7460	30.6	.8469	44.5						12.0
United Oil Co., Florence, Colo.	2445		.8750	30.0		122	1.5		27.0	.7988	70.2	.9079	98.7			9.23	
Boulder County, Colo.			.8304	38.6			16.0	.7368	40.0	.8000	44.0						
W. C. Jones, Robinson, Ill.	1140		.8490	34.9	Dark Green	95	13.0	.7386	37.0	.8028	50.2	.9235	97.2			3.71	1.56

LOCATION OF WELL	DEPTH OF WELL (FEET)	LOCATION OF POOL	PHYSICAL PROPERTIES			DISTILLATION BY ENGLER'S METHOD 100 CC. AT 60° F. TAKEN								UNSATURATED HYDROCARBONS		PARAFFIN (PER CENT)	ASPHALT (PER CENT)
			GRAVITY AT 60° F.		COLOR	BEGINS TO BOIL AT (° C.)	BY VOLUME										
							To 150° C.		150° TO 300° C.		RESIDUUM		TOTAL (CUBIC CENTIMETERS)				
			Specific	Degrees Baumé			Cubic Centimeters	Specific Gravity	Cubic Centimeters	Specific Gravity	Cubic Centimeters	Specific Gravity		Crude (per cent)	150° to 300° (per cent)		
S. Spellbring farm, sec. 7, Ohio Oil Co., Ill.[14]	330		.846	31.5	Light Green	63° C.	14.0	.7745	31.0	.8145							
J. Turner lease, sec. 33, Ohio Oil Co., Ill.[15]	300		.879	29.3	Brown	65° C.	8.0	.7008	27.0	.8268							
M. Misner lease, Pure Oil Co., Ill.[16]	606		863	32.2	Light Green	75° C.	18.0	.7193	32.0	.8065							
Z. E. Brant farm, sec. 26, Ohio Oil Co., Ill.[17]	480		868	31.3	Light Green	75° C.	10.5	.7261	30.5	.8141							
Chanute Pool, Beach lease, Rex Oil and Gas Co., Chanute, Kas.	751		.8647	31.9	Dark Green	109	5.0	.7350	36.0	.7993	57.8	.9223	98.8			4.25	1.23
Webb lease, Northland Oil and Gas Co., Erie, Kas.			.8739	30.2	Black	135	1.0		34.0	.8000	64.1	.9115	99.1			4.78	3.20
M. Davis lease, Dunkley & Odell, Coffeyville, Kas.	625	Coffeyville Pool	.8717	30.6	Black	100	6.0	.7289	33.0	.8030	58.3	.9241	97.3	24.4		5.31	0.17
F. G. Hill's lease, Interstate Oil and Gas Co., Peru, Kas.	1070	Peru Pool	.8557	33.6	Dark Green	110	7.0	.7310	37.0	.7975	63.2	.9150	97.2	24.8		5.79	1.53
McKinley Crude Oil Co., Humboldt, Kas.		Humboldt Pool	.8878	27.7	Dark Green	123	1.0		29.0	.8152	68.9	.9247	98.9	32.8	2	3.93	2.33
Springer lease, Hardison & Streeter, Rantoul, Kas.	350	Rantoul Pool	.8557	33.6	Black	76	11.5	.7116	29.5	.7950	54.9	.9272	95.9	34.0		3.45	2.29

Warren County and Sunnyside, Ky. . .			.8426	36.2		67° C.	19.0		37.0		44.0						
H. M. Caldwell, Monticello, Ky.			.8211	40.5	Dark Green	67	16.0	.7148	37.5	.9979	41.2	.9150	94.7			4.93	.41
Caddo Oil and Mineral Co., Gilbert well, La.			.8264	39.4	Black	136	1.5		49.0	.7778	49.1	.8805	99.6				.25
St. Martin's Parish, Anse-Le-Butte, La.[18]	600		.9392	19.1		240° C.			16.0		84.0						
Calcasieu Parish, Jennings, La.[19]. . . .	1000		.9093	24.0		200° C.			41.0		59.0						5.0
St. Claire County, Port Huron, Mich. . . .			.8333	38.0	Dark Green		15.0		55.0		30.0						
Lima, Ohio			.791	47.0	Dark Green	23° C.	16.0	.700	68.0	.788	16.0						
Washington County, Macksburg, O. . .	From 140 feet sand		.8118	42.5	Light Amber		15.47		[2]45.81								
New field, Evans lease, Julia Oil Co., Muskogee, Okla.	1553		.8328	38.1	Green	97	11.0	.7332	36.0	.7960	52.8	.8866	99.8			7.64	.0
Bartlesville pool, lot 32, Illuminating Oil Co., Bartlesville, Okla. .	1500		.8547	33.8	Dark Green	113	3.5	.7514	44.0	.7868	52.4	.9009	99.9			7.90	1.12
J. I. Yorgee lease, Robt. Galbreath, Tulsa, Okla. . . .	601	Red Fork Pool	.8323	38.2	Dark Green	93	9.0	.7220	40.5	.7814	48.5	.9038	98.0	17.6	1	4.39	.0
Thos. Berryhill lease, Indiana Oil and Gas Co., Kiefer, Okla. .	1518	Glenn Pool	.8439	35.9	Black	105	8.0	.7508	44.5	.8008	48.0	.9091	100.5	20.8	6	7.53	.90
W. B. Self lease, Prairie Oil and Gas Co., Tulsa, Okla. . . .	1523	Glenn Pool	.8373	37.2	Black	94	10.0	.7328	41.0	.7968	47.6	.9021	98.6	16.8	5	3.12	.21
Prairie Oil and Gas Co., Morris, Okla. . . .		Morris Pool	.8459	35.5	Light Green	112	3.0		34.0	.7924	62.1	.8866	99.1	10.0	1	11.90	.0
Buchanan lease, Burns & Caton, Morris, Okla.	1680	Bald Hill Pool	.8531	34.1	Dark Green	110	5.5	.7515	36.0	.8018	58.0	.9003	99.5	20.0	8	3.43	.15
Fort Worth Development Co., lease of Richmond Dev. Co., Muskogee, Okla. . .	1702	Muskogee Pool new field	.8333	38.0	Green	90	11.0	.7090	37.0	.7986	51.2	.8861	99.2	16.4	8	1.52	.0
Prairie Oil and Gas Co., Bartlesville, Okla. .		Bartlesville Pool	.8521	34.3	Dark Green	103	8.0	.7378	37.0	.8090	54.5	.9038	99.5	24.4	4	3.75	.23
Venango County, Pa.[20]			.882	28.7	Dark Brown		8.55		[1]42.78		[2]48.67						
Jefferson County, Beaumont, Tex. . .			.9217	21.9			1.8		17.1		81.1						7.5

LOCATION OF WELL	DEPTH OF WELL (FEET)	LOCATION OF POOL	PHYSICAL PROPERTIES			DISTILLATION BY ENGLER'S METHOD 100 CC. AT 60° F. TAKEN								UNSATURATED HYDROCARBONS		PARAFFIN (PER CENT)	ASPHALT (PER CENT)
			GRAVITY AT 60° F.		COLOR	BEGINS TO BOIL AT (°C.)	BY VOLUME										
							To 150° C.		150° TO 300° C.		RESIDUUM		TOTAL (CUBIC CENTIMETERS)				
			Specific	Degrees Baumé			Cubic Centimeters	Specific Gravity	Cubic Centimeters	Specific Gravity	Cubic Centimeters	Specific Gravity		Crude (per cent)	150° to 300° (per cent)		
Jefferson County, Beaumont, Tex. . .			.9206	22.1	Brown Opaque		6.45		35.0	.872	58.55						6.34
Navarro County, Corsicana, Tex.[21] . . .			.8604	32.7	Dark Brown	77° C.	^{1}24.78	.755	^{2}59.94		15.28						
Smith Bros. & Sweeney, St. Mary's, W. Va. .	1234		.7883	47.6	Green	73	15.0	.7076	43.5	.7688	39.4	.8578	97.9			9.00	.00
J. D. Dinsmore & Co., Big Injun Sand, St. Mary's, W. Va. . .	1673		.7870	47.9	Green	70	16.5	.7111	41.0	.7694	34.5	.8573	92.0			5.00	.00
Ohio and W. Va. Oil Co., 1st Cow Run Sand, St. Mary's, W. Va.	590		.8041	44.1	Green	89	18.0	.7256	39.5	.7818	42.8	.8653	100.3			8.92	.00
Dinsmore Oil Co., 1st Cow Run Sand, St. Mary's, W. Va. . .			.7982	45.4	Green	74	8.0	.7165	43.5	.7686	42.4	.8613	94.0			6.93	.00
Uinta County, Spring Valley, Wyo. . . .							28.0		24.0		48.0						
Oil Spring reserve, No. 12 Shale Spring, Wyo.			.8573	33.3	Light Green	143	tr.		51.0	.8271	48.7	.8929	99.7				

(1) Sulphur trace; paraffin base. (2) S, .098. (3) ^{1}, 150°–350° C. (4) ^{1}, 49°–141° C.; ^{2}, 141°–275° C. Asphaltic base. (5) S, .062. ^{1}, 150°–270° C. (6) S, .94. (7) S, .87; ^{1}, 150°–350° C. (8) S, 1.253; ^{1}, 150°–270° C. (9) S, .49. (10) Gravity at 15° C. (11) S, .36; gravity at 15° C. (12) S, 4.43; gravity at 15° C. (13) S, 1.56; gravity at 15° C. (14) S, .48. (15) S, .30. (16) S, .30; lower sand oil. (17) S, 27; upper sand oil. (18) S, 20; asphaltic base. (19) S, 39; asphaltic base. (20) ^{1}, 150°–270° C.; ^{2}, includes loss and water. (21) ^{1}, portion of fraction 77–203° F., lost before measured; ^{2}, 150°–280° C.

The following analyses represent a number of American occurrences. It will be seen that marsh gas is the predominating constituent in nearly all of them.

ANALYSES OF NATURAL GAS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Methane	94.40	96.20	82.25	14.85	62.93	95.35	13.97	73.81	92.67	92.61	90.01	98.90	80.94	86.48	98.40	94.2
Ethane (C_2H_6) . .	0.00	.78	0.00	.41	—		—		—	—			14.60	7.65	—	0.00
Olefine (C_2H_4) . .	0.00	0.00	.12	—	—		—		.25	.30			—	—	—	.39
Carbon Dioxide (CO_2)	0.00	0.00	.61	0.00	.50	1.60	.10	.81	.25	.26	.20	.40	—	—	—	1.06
Carbon Monoxide (CO)	0.00	0.11	0.00	0.00	tr.	2.50	.05		.45	.50			.40	.50	.95	1.13
Oxygen	.23	tr.	tr.	.20	.70	.55	.05	3.46	.35	.34	tr.	—	.20	.30	tr.	.92
						under	and C									
Nitrogen . . .	5.08	2.46	16.40	82.70	24.36	CH_4	85.83	21.92	3.53	3.61	9.79	.70	3.46	4.87	.40	3.31
Hydrogen . . .	0.00	.18	0.00	tr.	11.51	—	—	—	2.35	2.18	0.00	—	tr.	—	tr.	0.00
Helium	.183	.27	.616	1.84	U	N	D	E	T	E	R	M	I N	E	D	tr.
Hydrogen Sulphide	—	—	—	—	—	—	—	—	.15	.20	—	—	—	—	—	—

1. Iola, Kas., p. 270.
2. Buffalo, Kas., p. 270.
3. Fredonia, Kas., p. 270.
4. Dexter, Kas., p. 270.
5. Stockton, Cal., p. 252.
6. From glacial drift, Dawson, Ia., p. 252.
7. Princeton, Ill., p. 251.
8. Pittsfield, Ill., p. 251.
9. Muncie, Ind., p. 249.
10. Trenton limestone, Findlay, O., p. 248.
11. Kane, McKean Co., Pa., p. 247.
12. Pittsburg, Pa., p. 247.
13. Big Injun Sand, Shinnston, W. Va., p. 242.
14. Fifty Foot Sand, same locality, p. 242.
15. Trenton limestone, Baldwinsville, N. Y., p. 241.
16. Gas from coal mine, Scranton, Pa.

These analyses all quoted by Kansas Geological Survey, on pages given after each.

The gas from Dexter, Kansas, (No. 4 of the preceding table) is interesting because of its high content of nitrogen. Of 47 samples of gas examined[1] by Cady and McFarland, all except one showed helium, in amounts averaging .10 per cent. One Kansas sample contained 1.84 per cent more than the others, and this same one carried the high nitrogen contents referred to above. The rare element neon was also discovered.

The following table brings out the essential differences between natural gas and other fuel or illuminating gases.

Analyses of natural and manufactured gases.

	AVER. PA. & W. VA.	AVER. O. & IND.	AVER. KAS.	AVER. COAL GAS	AVER. WATER GAS	AVER. PRODUCER GAS BIT. COAL
Marsh Gas, CH^4 .	80.85	93.60	93.65	40.00	2.00	2.05
Other hydrocarbons	14.00	.30	.25	4.00	.00	.04
N	4.60	3.60	4.80	2.05	2.00	56.26
CO^2	.05	.20	.30	.45	4.00	2.60
CO	.40	.50	1.00	6.00	45.00	27.00
H	.10	1.50	.00	46.00	45.00	12.00
H^2S	.00	.15	.00	.00	.00	.00
O	tr.	.15	.00	1.50	1.50	.05
Lbs. in 1000 cu. ft. .	47.50	48.50	49.00	33.00	45.60	75.00
Sp. gr.	.624	.637	.645	.453	.600	.985
B.T.U. per 1000 cu. ft.	1,145,000	1,095,000	1,100,000	755,000	350,000	155,000

Origin of Oil and Gas. — That the solid, liquid, and gaseous hydrocarbons are more or less closely related is evident from the fact that the gases given off by petroleum are similar to those predominating in natural gas, while the exposure of many petroleums to the air results in a change to a viscous mass and finally to a solid asphalt or paraffin-like substance. It is a well-known fact that petroleum is rarely free from natural gas, although this gas may sometimes form alone, as in coal mines, or from decaying vegetation in stagnant pools. The origin of the hydrocarbon compounds has been the subject of much speculation among both chemists and geologists, the former for a time arguing for an inorganic or mineral origin, the latter for an organic derivation, the same evidence curiously enough being sometimes used by persons holding opposite views.

It cannot be said that the matter has yet been settled to the satisfaction of all, although it is probable that the majority of observers admit the organic origin of petroleum. One cause of uncertainty is that oils, unlike coals, do not usually contain visible traces of their original constituents. Moreover, we had until recently few undoubted known instances of the recent formation of petroleum under conditions similar to those found in the older rocks.

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[1] Jour. Amer. Chem. Soc., XXIX : 1524.

Inorganic Theories (1, 3*a*, 10). — Several theories have been advanced to account for an inorganic origin of oil. Berthelot was perhaps the first to advance a general theory,[1] but that of Mendeljeff[2] is somewhat better known, and is in a way an elaboration of some of the earlier ones. According to this theory, the interior of the earth contains metallic iron, as well as carbide of iron like that found in meteorites. Water percolating downward through the earth's crust, on reaching the heated interior, becomes converted into steam, which, attacking the carbide of iron, forms hydrocarbons. These are forced to the surface by the expansive force of the steam.

From a purely chemical standpoint, this theory is reasonable, and the production of hydrocarbons by this method has been done experimentally, but it does not accord with geologic facts. If petroleum were formed in this manner, we should expect to find it widely distributed through the oldest rocks of the earth's crust.

On the contrary, hydrocarbon compounds like oil, gas, and asphalt are practically unknown in crystalline rocks. In Ontario, a hard compressed asphalt is found in them, but it is significant that this material (Anthraxolite) which was probably originally petroleum, occurs in rocks which may be metamorphosed sediments. A second case is found in California (17), where oil occurs in a much-folded crystalline schist, but its associations are such that it may have been derived from neighboring sediments.

A possible point in favor of the derivation of oil and gas from carbides has been noted by Becker (1), who has called attention to the fact that the irregularities of the curves of equal magnetic declination are strongly marked in the principal oil regions. While the agreement is not a very close one, it is most marked in the Appalachian field. There are, however, some systematic irregularities, as in the New Jersey magnetite regions, which are not known to contain any oil. Becker believes that the coincidence between the petroleum occurrences and local disturbances of the compass are too numerous to be attributable to mere accident, and that there must be a direct or indirect historical connection between the two phenomena in the regions of coincidence, thus suggesting the possibility of the oil being derived from iron carbides.

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[1] Compt. Rend., LXII : 949, 1866.

[2] Ber. Deutsch. Chem. Gesell., X : 229, 1877, and Jour. Chem. Soc., XXXII : 283.

Volcanic Theory. — A second inorganic theory advocated by several, and in recent years expounded with great vigor and detail by E. Coste (3*a*), is the theory of volcanic origin of the hydrocarbons.

Mr. Coste believes that all hydrocarbons cannot be of animal or vegetable origin, but must be of volcanic derivation for the following reasons: 1. Animal remains are never entombed in rock formations. 2. Vegetable remains in rocks decompose into carbonaceous matter. 3. Further distillation of carbonaceous matter has not taken place in nature. 4. Gaseous, liquid, and solid hydrocarbons are products of volcanic emanations. 5. Oil and gas are under strong pressure, and hence must be of volcanic origin, for nothing else could produce this pressure. 6. In some oil fields heated gas and water are met with. 7. Oil and gas fields are located along faulted and fissured zones of the earth's crust, parallel to great orogenic (mountain-making) and volcanic dislocations. 8. Oil, gas, and bituminous matter are never indigenous to the strata in which they are found. 9. The density of the rocks precludes possibility of anything but volcanic pressure having forced them upward.

The arguments against some of these points may be mentioned under the same numbers: 1. Animal remains are entombed in rocks, otherwise we could not have fossils of those lacking hard parts. 2. Vegetable remains in rock have been proven to decompose into hydrocarbons, as evidenced by natural gas supplies found in glacial drift; moreover, some coal seams have oil seepages. 3. While hydrocarbons are known to occur in some volcanic emanations, they might be formed by the direct union of carbon and hydrogen of these gases, or have been distilled out of sedimentary rocks through which the lava passed. Moreover, they are frequently formed from decaying vegetable matter. 5. The pressure may be due to the natural expansive force of the gas. 7. Oil and gas fields are sometimes found in regions of but little disturbance, as Illinois, Medicine Hat, Alberta, etc. 8. This may be true, but they are often clearly shown to have come from adjoining beds. 9. If volcanic pressure forced this oil and gas up through many feet of dense rock, why were they not forced all the way to the surface?

One may also add that the restriction of oil and gas to sedimentary rocks is not in accordance with a volcanic origin, neither is the decrease in pressure which all wells show with time.

Organic Theory. — This considers that petroleum has been derived from either animal or vegetable matter by a process of slow distillation, although the exact changes involved are somewhat uncertain.

Perhaps the majority of geologists and even others have unconsciously assumed that petroleum has been derived from land plants, and while in some cases this may be so, some rather weighty objections can be urged against it. These are the following: —

1. There is a general lack of association of coal or lignite and oil. 2. Where lignite or carbonized wood is found with oil it has lost none of its essential constituents. 3. There is a great chemical difference

between lignite tar oils and natural petroleums. 4. It requires a high temperature (geologically speaking) to convert wood into liquid bitumen, and leave no trace of its original structure.[1] 5. An argument of doubtful weight is that limestones, being of marine origin, the oil in them could not be derived from land plants.

The following arguments may be mentioned in favor of the derivation of petroleum from marine plants such as seaweeds: 1. Saline water associated with some oils carries iodine.[2] 2. Certain seaweeds found on the coast of Sardinia become covered with an oily coating while decomposing.[3] 3. The Boghead mineral, or Torbanite, and the kerosene shale of Scotland are derived from gelatinous algæ whose remains are embedded in what was once a brown humic jelly.[4] 4. In some localities the diatom cases found in rocks are known to contain small globules of oil, which have in some regions been regarded as a source of petroleum (19).

Some have also considered that the oil may have been derived, in part at least, from animal remains, the oil having thus a dual origin.

Recent investigations of the optical activity of oil show it to be of undoubted organic origin (1), for the reason that many petroleum products have the power of rotating the plane of polarization of light, as is done by sugar, lactic acid, and other organic compounds. These optical phenomena are not shown by inorganically synthesized petroleum, and hence it is argued that the substances to which it is believed to be due are only of organic derivation. These substances are phytosterol, found in the fatty parts of animals, and cholesterol, found in plants.

If the oils are derived from animal and plant remains of marine character, it is possible that the nitrogenous portions were eliminated by bacterial action soon after the death of the organism, and before it became buried under sediments. Subsequently the oil was produced by decomposition of the fatty matter of the plants and animals. Some geologists, including Orton (4) and Newberry (Ohio State Agric. Rept. 1859), have believed that the formation of petroleum has taken place at lower temperatures; but others, including Peckham (6), have considered heat necessary. In the case of

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[1] Such a process would only be likely to occur where a bed of land plants was approached by an intrusive.

[2] Watts, Calif. State Min. Bur., Bull. 19 : 202.

[3] Redwood, Petroleum and its Products, 2d edition, I, 126, 142.

[4] Comp. Rend., CXVII: 593, 1893, and Compt. Rend., VIII, Cong. Geol. Internat. 1900 : 458.

Appalachian oils the folding of the strata is supposed to have supplied this heat.

Mode of Occurrence (6, 8, 9, 13). — Oil is rarely found without gas, and saline water is likewise often present. If the containing strata are horizontal, the oil and gas are usually irregularly scattered, but if tilted or folded, and the beds porous throughout, they appear to collect at the highest point possible. It was the result of observations along this line that led I. C. White to develop what is known as the "Anticlinal Theory" (13). According to this theory, in folded areas the gas collects at the summit of the fold, with the oil immediately below, on either side, followed by the water (Fig. 22). It is of course necessary that the oil-bearing stratum shall be capped by a practically impervious one.

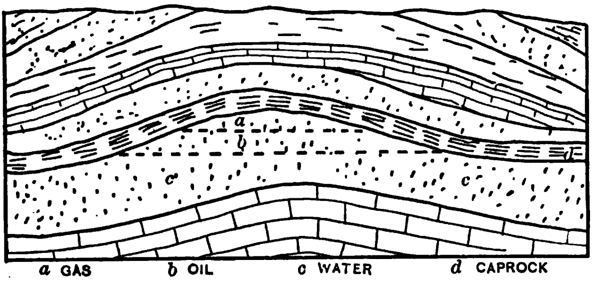

FIG. 22. — Section of anticlinal fold showing accumulation of gas, oil, and water. (*After Hayes, U. S. Geol. Surv., Bull.* 212.)

If the rocks are dry, then the chief points of accumulation of the oil will be at or near the bottom of the syncline, or lowest portion of the porous bed. If the rocks are partially saturated with water, then the oil accumulates at the upper level of saturation.

In a tilted bed, which is locally porous, and not so throughout, the oil, gas, and water may arrange themselves according to their gravity in this porous part.

While the anticlinal theory has been found to apply in most oil regions, some doubt has been raised regarding its possible application in parts of southwestern Pennsylvania (6).

Lesley and Ashburner suggested that the porous areas in which the oil and gas accumulated represented old shore line deposits.

In the first discovered fields, the oil and gas were found in porous, sandy strata, varying from fine-grained sandstones to conglomerates. These rocks were termed *sands*, and the area of porous oil sand was called the *pool*. Later discoveries in Ohio and Indiana showed that the gas and oil might occur in limestone also, while in a few fields (Florence, Colorado, and parts of California) the oil has accumulated in fissures in shale, produced by earth movement.

The number and thickness of the oil and gas sands may sometimes vary in different parts of the same field (Figs. 23 and 24), thereby making correlation difficult.

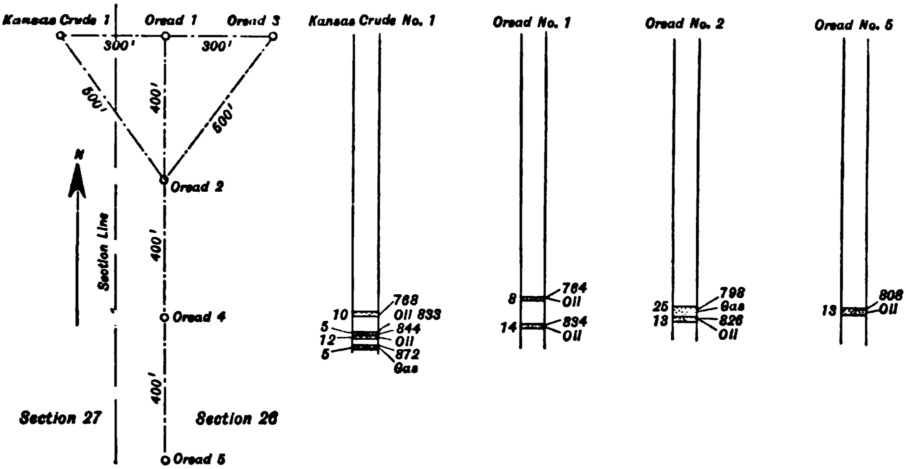

FIG. 23. — Showing positions and vertical sections of wells southeast of Humboldt, Kas., and differing thickness and number of sands in neighboring wells. (*Kas. Geol. Surv., IX.*)

The thickness of the producing rock (" pay sand ") varies in the different fields. White, referring to West Virginia, regards 5 feet of sand as sufficient for good productive territory, but thicker ones are found in the Appalachian field. The Illinois sands range from 2 to over 30 feet in thickness, while that estimated for Spindle Top in Texas averages 75 feet. The Kern River field of California is said to have pay sands as much as 100 feet thick.[1]

The quantity of oil which a cubic foot of apparently dense rock can hold is often surprising. White estimated that fairly productive sands may hold from six to twelve pints of oil per cubic foot, but that probably not more than three-fourths of the quantity stored in the rock is obtainable. According to Day (53) it has been customary to consider 10 per cent as near the average porosity of the pay sand, with a latitude of variation from practically nothing in damp shales to over 30 per cent in the most porous strata. The

[1] Day, U. S. G. S., Bull. 394 : 34, 1909.

degree of openness of the pores will, however, govern the rate of flow of oil from the rock.

Pressure of Oil and Gas Wells. — Since both oil and gas usually occur in the earth under pressure, any break in the porous rock or reservoir which contains them allows them to escape, frequently giving rise to surface indications, and the force with which oil and gas oftentimes issue from a well indicates the pressure under which they are confined. It is sometimes sufficient to blow out the drilling tools and casing, as well as to cause the oil to spout many feet into the air.

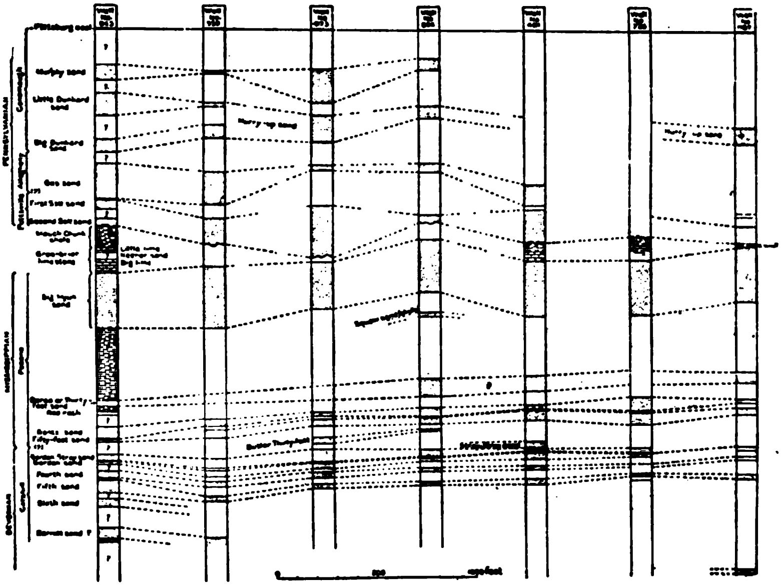

FIG. 24. — Sections of deep wells in the Clayville, Pa., quadrangle, showing irregularity in thickness and number of the oil and gas sands. (*After Griswold and Munn.*)

There are several remarkable cases of the amount spouted by these gushing wells. One of these is the famous Lucas well at Beaumont, Texas, which in 1901 for nine days gushed a six-inch stream to a height of 160 feet, at the rate of 75,000 barrels per day. This, however, is small compared with the records of some Russian oil wells. Although many wells flow when first drilled, this does not usually continue long, and the oil then has to be brought to the surface by pumping. The depth of the wells drilled in the United States ranges from 250 to 4000 feet.

The maximum pressure which a well develops when closed has been called *rock pressure.* As a result of his studies in the Ohio-

Indiana field, Orton (42) found that the rock pressure was the same as that of a column of water whose height was equal to the difference in elevation between the level of Lake Erie and that of the oil or gas-bearing stratum. He therefore considered it to be hydrostatic pressure. This theory, while apparently applicable in many localities, was found to be inadequate to explain the great pressure shown in many shallow wells. In these, as also in deep ones, the pressure is thought by many to be due to the expansive force of the imprisoned gas.

Either the drilling of additional wells or a drain by excessive use from wells already bored commonly causes a slow decrease in pressure in an oil or gas field. Thus in the natural gas region of Findlay, Ohio, the rock pressure in 1885 was 450 pounds per square inch; 400 in 1886; 360–380 in 1887; 250 in 1889; 170–200 in 1890. Some West Virginia wells have shown a measured rock pressure of 1110 pounds per square inch and an estimated pressure of 2000 pounds.

It has been not infrequently noticed, however, that the opening up of one or more wells close to a good producer may have little or no effect on it.

The table on page 66 (53) gives the closed or rock pressure in various fields, in different years. They are interesting, but lose their comparative value as they do not probably in all cases represent the same well.

Mode of Accumulation. — While the oil and gas are not necessarily, and probably rarely, indigenous to the rock containing them, a difference of opinion exists as to whether they have been transported long distances; indeed their source is often indicated in some under- or over-lying bed of shale.

If this be true, then, in order to reach the sandstone, they must in part at least pass through the small pores of the shales, but the nature and cause of this movement are not clearly understood. Capillary action and great rock pressure have been suggested as possible operating forces, while Munn believes it is caused by hydraulic action. According to his hydraulic theory (6), the diffused oil and gas are concentrated into pools or pay streaks by the action of currents of underground water. These collect the oil and gas and push them along. Since these underground currents circulating through the rocks vary in the direction of their flow, there may be places where the meeting of conflicting currents form eddies or places of no movement. It is at such points that the accumulated oil and gas are held. If the water is flowing

PRESSURE OF NATURAL GAS IN VARIOUS FIELDS AT VARIOUS DATES

(In pounds per square inch)

	ILL.	IND.	KAS.	KY.	N.Y.	O.	OKLA.	PENN.	TEX.	W. VA.
1885	400–450					450		150–575		
1886	125	325–400	110			400		200–460		550–680
1887		320–340				[1]750 [2]650		200–380		
1888	300	325		125		[2]450				
1889		325			400	250–390				
1890					240	170–275				1000
1893		280								
1894	60	260	200					250		
1895	40	240		[3]60 [4]250–300		[2]50–150		150		
1896	25	220	100	285–300		[1]750 [2]45		85		600–900
1897		195	250		1500	[2]30				100–1100
1898		165								600–1200
1899	[5]3–30	150	300–325		200					1200
1900		110	[6]310–320 [7]150			[1]300–400 ([2], [8])				1200
1901		80							[9]250	1000–1300
1902		50				[1]100 [10]800				1000–1250
1903								400		850–1250
1904		155 [11]305–400	550–650							
1906	150–435	22–156	90–282		45–335	121–352	217–468	41–486		144–516

[1] Lancaster. [2] Northwestern Ohio. [3] Western Kentucky. [4] Eastern Kentucky. [5] Bureau County. [6] Allen County. [7] Neosho County. [8] Reduced to almost no pressure. [9] Beaumont. [10] Homer. [11] Southern Indiana.

through the rocks under the influence of capillarity alone, and conflicting currents are absent, there will be a tendency to force the oil and gas into the more porous beds where the capillarity is too weak for the water to follow.

The pressure of the oil is ascribed to the expansive force of the gas, which cannot diffuse because of the saturation of the surrounding rocks. The association of oil with anticlines is thought to be due to the influence which these structures exert on the water currents. The difference in specific gravity of oil and water is considered insufficient to account for the widespread movement of oil against the friction developed by its passage through rock pores.

The oil and gas are, then, held in the rock, not because of an impervious cap rock, but by the overlying and surrounding water mantle.

Yield of Sands. — A porosity of 10 per cent would mean a theoretical yield of about 1 gallon per cubic foot, or about 5000 barrels per acre with a 5-foot thickness.

Although many Pennsylvania sands are thicker than 5 feet, the figures of production indicate an average yield in the past of not much over 800 barrels per acre, but the average for the entire Appalachian field may be taken as slightly greater. Bain estimates 2000 barrels per acre for Illinois.

However, it is a difficult and conjectural matter to estimate closely the average yield of oil in any field.

Life of a Well. — This may vary with the amount of supply, compactness of pay sand, and gas pressure accompanying the petroleum. It varies from a few months to 20 years or more. Some wells may gush forth tremendous quantities of oil and gas for a short period and then die down to almost nothing. Others may yield moderate quantities, or perhaps only a few barrels daily, for a period of years. The average life of Pennsylvania wells is seven years.

In all fields the production increases at first and then begins to drop off, and the increasing production of the United States is due to the discovery and development of new fields, whose production more than offsets the decrease of the older ones.

As examples, the daily average production per well per day of New York and Pennsylvania has fallen from a maximum of 207 barrels to 1.7 barrels. The West Virginia production has dropped to 56 per cent of its maximum, and Ohio and Indiana have shown a still greater decline.

On the other hand, Illinois, Oklahoma, and California will probably increase.

Day (53) estimates that considering the minimum amount of petroleum in the United States as 15,000,000,000 barrels, the supply will be exhausted about 1935 with the present rate of increase in production. With stationary production, about 90 years would be required.

Distribution of Petroleum in the United States. — The important fields of the United States (Pl. VI) together with their approximate area in square miles is as follows (53): —

Appalachian	Tenn.	80	
	W. Va.	570	
	Ky.	400	
	N. Y.	300	
	Ohio	115	
	Pa.	2000	3465
Lima-Indiana	Ind.	1000	
	Ohio	535	1535
Illinois			200
Mid-Continental	Kas.	200	
	Mo.	30	
	Okla.	400	630
Gulf	La.	60	
	Tex.	400	460
California			850
Wyoming			750
Colorado			200
Michigan			80
			8170

These figures of course represent only the areas actually underlain by known pools, and not the entire area of the field.

Appalachian Field. — This is the largest oil field in the United States, and includes portions of New York, Pennsylvania, Ohio, West Virginia, Kentucky, and Tennessee.

The rocks are chiefly sandstones, with a few limestones, embedded in and underlain by a great thickness of shales, while below these are probably limestone beds. The sandstones have a thickness of probably 2000 feet or more, and in the middle and northern end of the field range from the Alleghany series nearly to the base of the Devonian, and still lower in Tennessee and Kentucky. Their deposition represents a period of continuous sedimentation, with the exception of the period between the Mauch Chunk and the Pottsville, where an unconformity indicates an interval of uplift and erosion.

It may be said of the Appalachian field as a whole that the oil-bearing rocks occupy the bottom and west side of a large structural trough, whose rim passes through central Ohio, then eastward south of the Great Lakes and then south along the western base of the

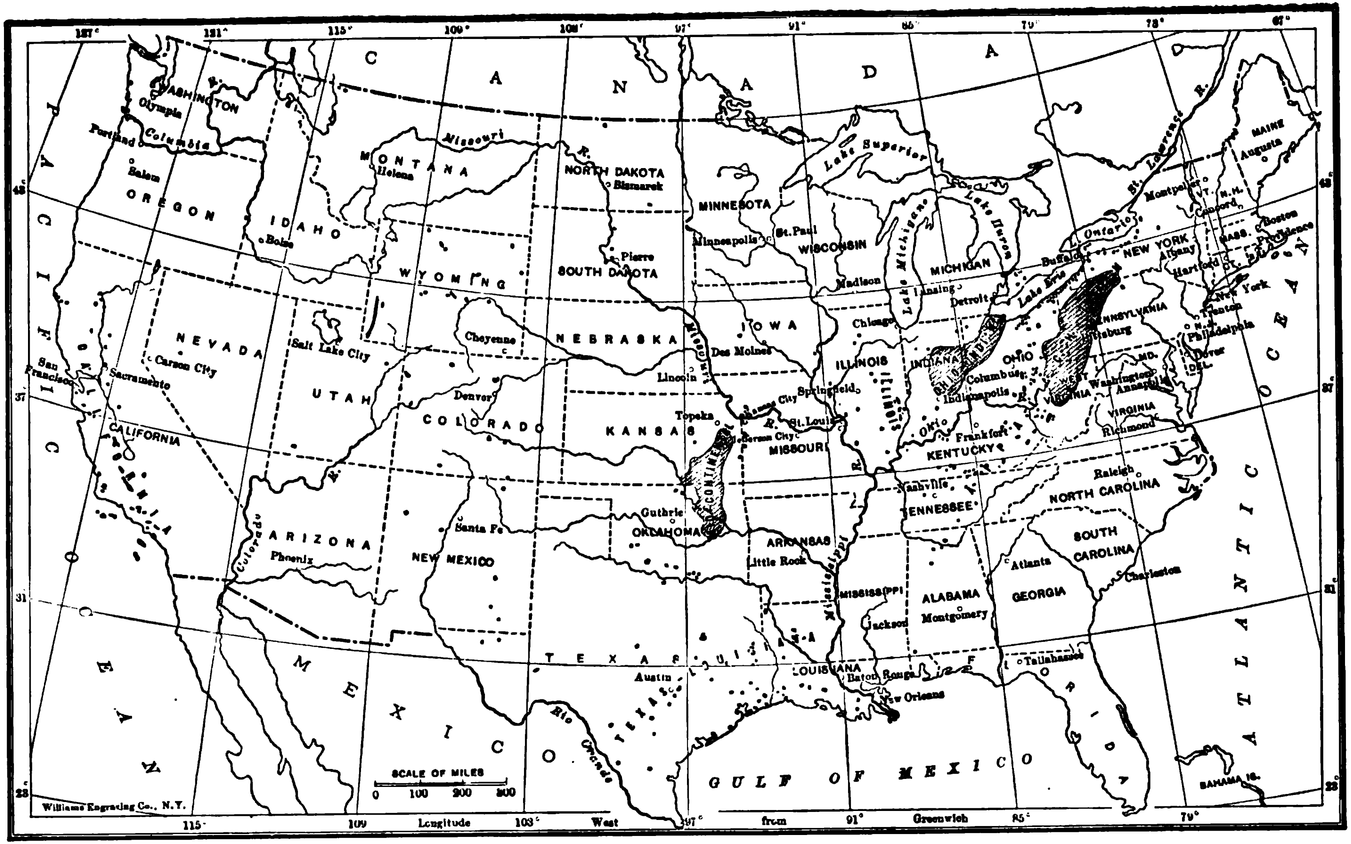

PLATE VI. — Map showing oil and gas fields of United States. (*After Day.*)

PLATE VII

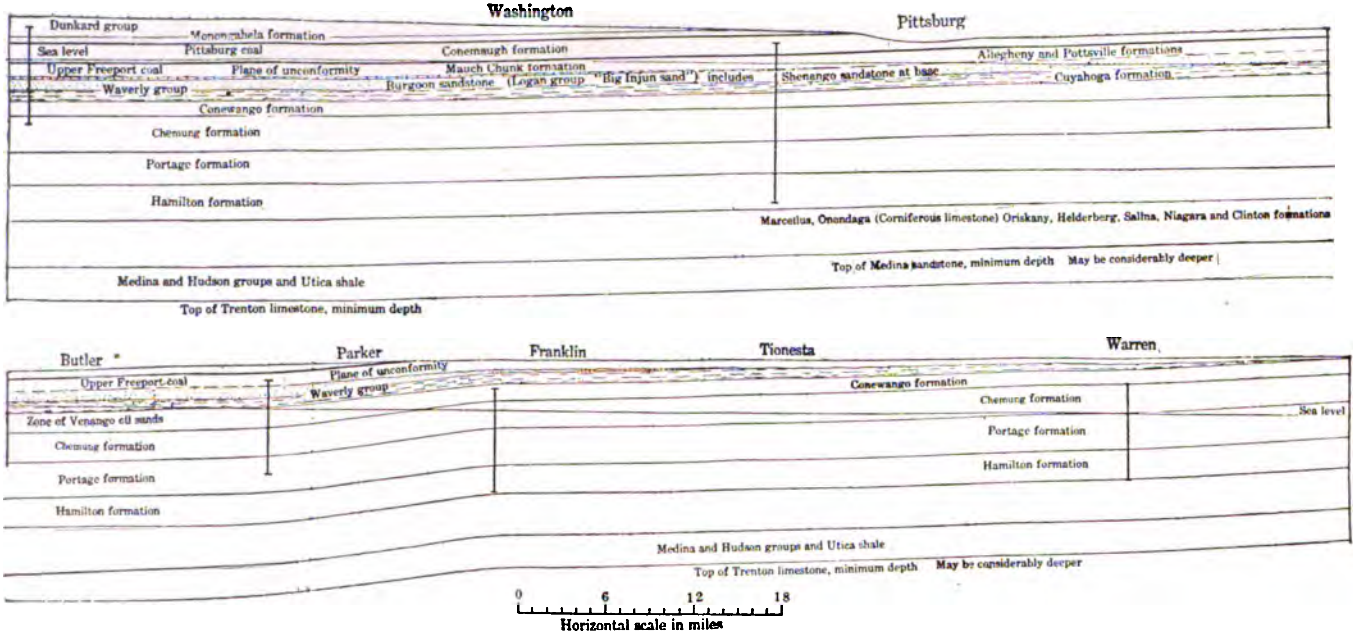
Washington
Pittsburg
Dunkard group
Monongahela formation
Sea level
Pittsburg coal
Conemaugh formation
Allegheny and Pottsville formations
Upper Freeport coal
Plane of unconformity
Mauch Chunk formation
Waverly group
Burgoon sandstone (Logan group "Big Injun sand") includes
Shenango sandstone at base
Cuyahoga formation
Conewango formation
Chemung formation
Portage formation
Hamilton formation
Marcellus, Onondaga (Corniferous limestone) Oriskany, Helderberg, Salina, Niagara and Clinton formations
Top of Medina sandstone, minimum depth May be considerably deeper
Medina and Hudson groups and Utica shale
Top of Trenton limestone, minimum depth
Butler
Parker
Franklin
Tionesta
Warren
Upper Freeport coal
Plane of unconformity
Waverly group
Conewango formation
Chemung formation
Sea level
Zone of Venango oil sands
Chemung formation
Portage formation
Portage formation
Hamilton formation
Hamilton formation
Medina and Hudson groups and Utica shale
Top of Trenton limestone, minimum depth
May be considerably deeper
0
6
12
18
Horizontal scale in miles

FIG. 1. — Geological section, along line AB in Fig. 25, showing general structure of coal- and oil-bearing formations. (*Pa. Top. and Geo. Com., Rept.* 1906–1908.)

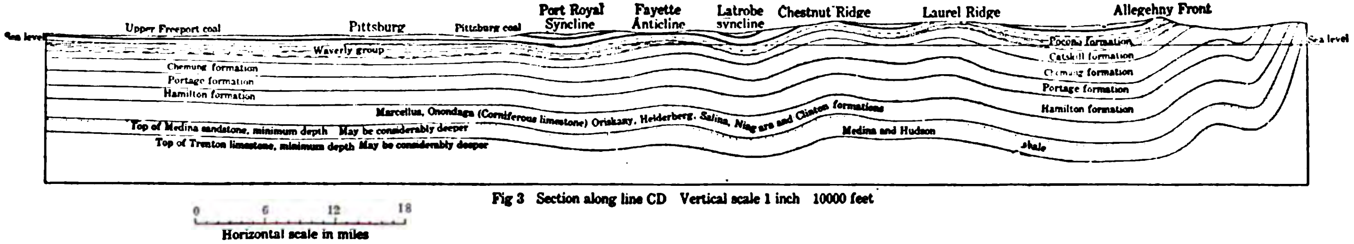

FIG. 2. — Northwest-southeast section across Appalachian coal and oil region of southwestern Pennsylvania. (*Pa. Top. and Geol. Com., Rept.* 1906–1908.)

Appalachians. It therefore crosses western Pennsylvania where petroleum has been found in large quantity. While the total area outlined is probably over 50,000 square miles, the area actually underlain by known oil-bearing sands does not appear to exceed 3500 (53).

Within this great trough there are a number of subordinate folds whose trend is northeast southwest, while still minor ones are found with their axes at right angles to these.

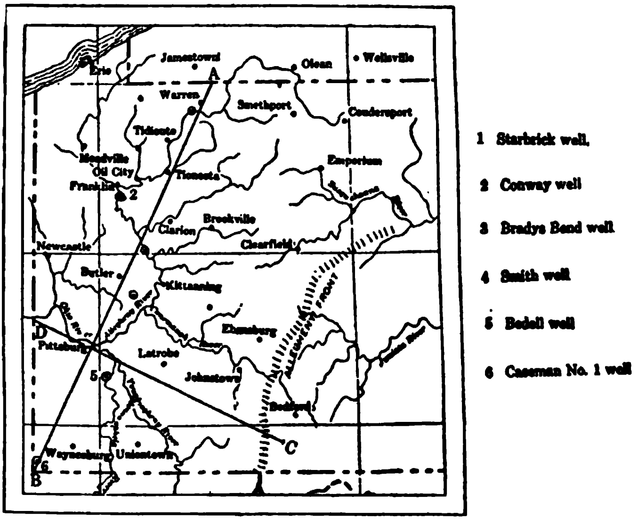

FIG. 25. — Map showing lines of sections in Plate VII.

The sandstones are, moreover, found at increasing depths as one goes southward, so that those outcropping in Ohio and New York may be 2000 or 3000 feet below the surface in southwestern Pennsylvania or West Virginia.

In this region there are a number of sandstones, the important ones individually underlying many square miles. These sandstones are most numerous and attain their greatest thickness in the center of the region.

The upper or younger sands are usually white, and may be conglomeratic locally, while the older beds are brown or reddish, and generally more uniform in texture.

At some localities two or more sands produce oil, and the lowest then may be the most prolific. The wells range in depth from 100 to 4000 feet.

The character of the oil found in this region is said by Dr. Day to differ essentially from any other petroleum thus far found in the world. It is practically free from sulphur and usually from asphalt, but is rich in paraffin wax. Added to this is its easy conversion into lamp oil, of which product it yields the greatest percentage, being far ahead of all others except the Lima and Ohio petroleums, which, however, are more expensive to refine.

The Kentucky and Tennessee product, while inferior to that found in Pennsylvania, is much better than the Russian or any other of the foreign products with which it has to compete.

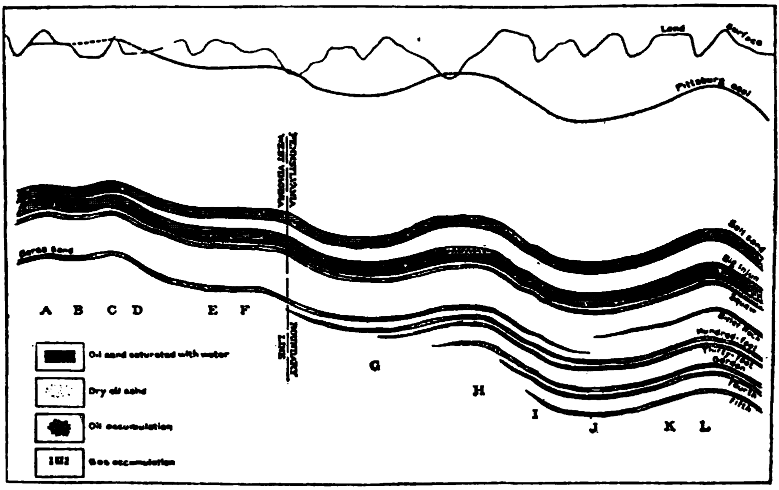

FIG. 26. — Diagramatic section of sands in the central Appalachian region. (*After Griswold and Munn, U. S. Geol. Surv., Bull.* 318.)

The Appalachian region, however, has passed the zenith of its production, that of Pennsylvania having been reached seventeen years ago; and yet some of the wells show a remarkably persistent, though small, production.

In New York State petroleum is obtained from the fine-grained sandstones of Chemung age in parts of Cattaraugus, Allegany, and Steuben counties. The wells range from 600 to 1800 feet in depth, and while of small capacity, they yield a product of good quality, which ranges from amber to black in color.

The petroleum-producing belt extends across Pennsylvania, in a southwesterly direction, leaving it in the southwestern corner. Within this area (whose general structure has been referred to above) there are a number of oil pools, occurring in rocks ranging from the Conemaugh series of the Carboniferous down to and including the

Chemung division of the Devonian. In the space permitted here, it is not possible to go into detail regarding all the pools. Suffice it, therefore, to say, that the oil is obtained from a number of different sands, some of which are of high importance, as the Berea, Hundred Foot, Fifth, etc.

In the table given on pages 72 and 73, an attempt has been made to show the oil (and gas) sands known in the different formations, but they are correlated only so far as occurring in the same formation.[1]

Ohio-Indiana Field (24-26, 39-44). — The discovery of oil and gas in the Trenton rocks of western Ohio in 1884 caused considerable excitement, since it showed the existence of petroleum in limestone, an exception to previously known conditions, and at a much lower geological horizon than any in which oil or gas had hitherto been found. This field extends from Findlay in northwestern Ohio southwestward into Indiana.

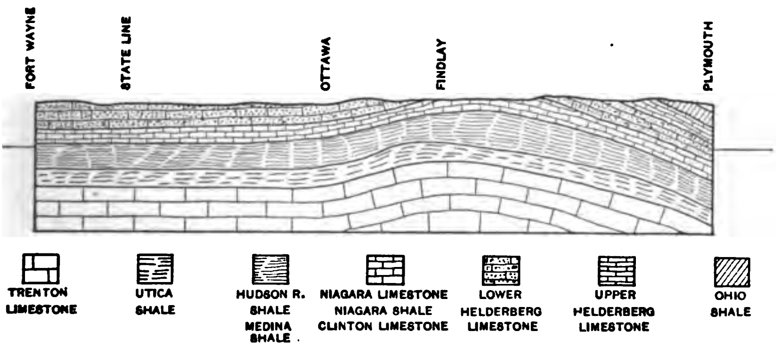
FORT WAYNE
STATE LINE
OTTAWA
FINDLAY
PLYMOUTH
TRENTON LIMESTONE
UTICA SHALE
HUDSON R. SHALE MEDINA SHALE
NIAGARA LIMESTONE NIAGARA SHALE CLINTON LIMESTONE
LOWER HELDERBERG LIMESTONE
UPPER HELDERBERG LIMESTONE
OHIO SHALE

FIG. 27. — Geological section of Ohio-Indiana oil and gas fields. (*After Orton, U. S. Geol. Surv., 8th Ann. Rept., II.*)

Most of the Trenton oil has been found in the upper 50 feet of the formation, in one of two thin streaks; but at several localities in both Ohio and Indiana, a productive horizon lying from 100 to 200 feet deeper has been discovered. The oils of this field contain sufficient sulphur to require special treatment for its elimination, but the oil is of paraffin base like that of the Appalachian region.

Outside of the main field, oil has been found in the Clinton formation of Ohio, the most important occurrence being in Vinton County (39). In Indiana oil has been obtained from the Corniferous limestone (Devonian) and from the Huron sandstone (Lower

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[1] These tables are those given by the respective state surveys.

CORRELATION OF OIL AND GAS SANDS IN APPALACHIAN FIELDS

	PENNSYLVANIA	WEST VIRGINIA	OHIO	KENTUCKY	NEW YORK
Monongahela.		Carroll.	Horseneck.		
Conemaugh.	Murphy. Little Dunkard. Big Dunkard. Cow Run or Hurry Up.	Morgantown. Moundsville. First Cow Run. Upper Dunkard. Lower Dunkard.	Mitchell. First Cow Run. Mahoning.		
Allegheny.	Gas sand.	Second Cow Run. "Gas" sand of Marion and Monongalia Counties.	Dunkard or 300 foot.		
Pottsville.	Salt sand, sixty foot.	"Gas" sand of Cairo. Salt sand, Cairo. (?)	Macksburg, 500 foot sand. Second Cow Run. Salt sand. Maxton.	Beaver Horton Pike Salt } Of Floyd, Pike, etc., Cos. Wages Jones Epperson } Knox Co.	
Mauch Chunk.	Little lime, Salvation or Maxton sand.	Maxton, Cairo. (?)		Big Injun. Cloverport. Berea Stray Mt. Pisgah Beaver Otter Cooper Slickford Amber ore } Wayne Co.	
Mountain or Greenbrier Limestone.		No oil or gas horizons except as part of the "Big Injun" below, unless the Beckett Sand of Milton Field belongs here.			
Pocono Sandstone.	Mountain or Big Injun. Squaw. Pappoose. Butler gas, Butler, 30 ft. Gas, Salt, Murrysville or Berea. (?) Gantz. Fifty foot. Hundred foot.	Keener. Big Injun. Squaw. Berea. Gantz. Fifty foot.	Keener. Big Injun. Squaw. Berea.		

Catskill.	Nineveh or thirty foot. Snee, Blue Monday or Stray Boulder, Gordon Stray or Campbell Run. (?) Gordon or Third. Fourth. Fifth (McDonald). Bayard or Sixth.	Thirty foot. Stray. Campbell's Run or Garden. Whetstone Run. Gordon sand. Flat Run. Gordon or Fourth. Fifth (McDonald). Bayard or Sixth.	Ohio Black shale (gas).		
Chemung.	Elizabeth Warren 1st sand. (?) Warren 2d sand. (?) Speechley. Tiona. Bradford first and second. Elk (?) sand. Kame (?) sand.				Oil and gas sands of southwestern New York.
Corniferous.				Ragland oil sand. Irvine oil sand. Menefee gas sand.	
Lower Helderberg.			Lower Helderberg.		
Clinton.			Clinton sand.	Clinton (Morgan Co.).	
Medina.					Gas sands of Erie Livingston Chautauqua Genesee Counties.
Hudson.				Caney Creek. Upper Sunnybrook. Deep. Shallow.	Utica shale-gas.
Trenton.			Trenton.	Lower Sunnybrook. Lower sands of Barren Wayne Clinton Cumberland Counties. Deep sand (Wayne Co.).	Limestone of Oswego and Onondaga Counties. Gas.
Calciferous.				Salt water sand at top. Gas sand (Estill Co.).	
Potsdam.					Some gas.

Carboniferous) in Gibson County. The latter occurrence is exceedingly pockety, and the oil, which is darker and thicker than the Trenton oil, has a low percentage of illuminants.

Ohio and Indiana show a much smaller production than formerly.

Illinois Field (23). — Oil and gas have been known in Illinois for some years, but the important discoveries were not made until 1904, and the production since then has increased at such a rapid rate that in 1908 it was exceeded only by that of the Mid-Continental and California regions.

As indicated by the map (Fig. 28), the approximate limits of the main producing territory extend from Clark and Cumberland counties southward through Crawford and into Lawrence, so that the productive strip has a proven length of approximately 80 miles, which, however, is not underlain throughout by oil. The limits may be extended in the future.

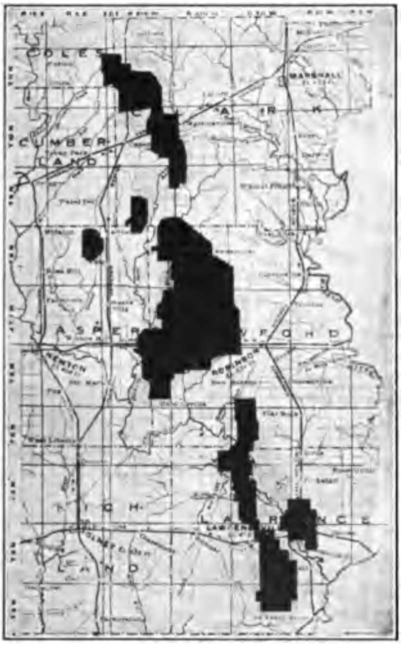

FIG. 28. — Map showing approximate area of oil fields in southeastern Illinois. (*After Bain, Ill. Geol. Surv., Bull.* 8.)

There has been no regular production in this field outside of these general limits, although oil has been found at a number of other points (23) in the state.

The principal horizons at which oil and gas have thus far been discovered are in the Carboniferous rocks, the sands occurring in both the Upper and Lower Coal Measures, the Pottsville group, and the Chester group (Lower Carboniferous or Mississippian). The exact identification of the beds and correlation of different sections in adjoining areas is often attended with difficulty.

The oil is usually found in sandstone, but the Westfield pool forms an interesting exception, for there it occurs in a locally dolomitized coal-measure limestone. A doubtful relation exists between the occurrence of the oil and anticlines.

PLATE VIII

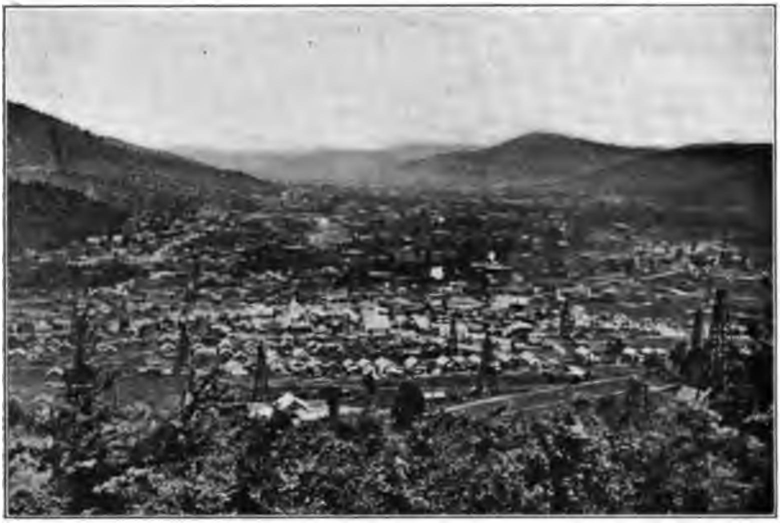

FIG. 1. — General view of Tuna Valley, in Pennsylvania oil field. (*Photo. by F. H. Oliphant.*)

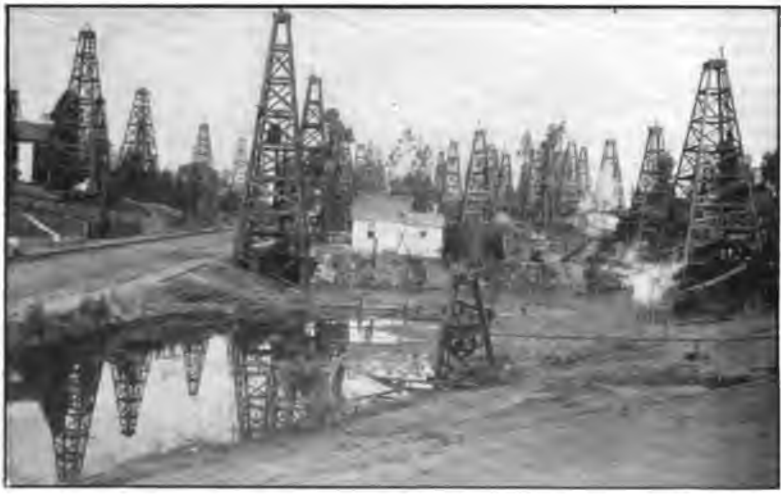

FIG. 2. — View in Los Angeles, Cal., oil field. Such close spacing of oil derricks tends to hasten the exhaustion of the oil supply.

In general the depth of the wells increases from north to south as follows: Oilfield pool, 300–350; Siggins pool, 400 and 570; Johnson township, 470 and 610; Crawford County, 900 to 1000; Lawrence County, 950, 1300, 1500.

The Illinois field is no longer included in the Ohio-Indiana region, because the oils are of different horizon. Moreover, the product carries less sulphur and much of it is refined without special treatment. Some of it contains asphalt as well as paraffin, and the oils vary within wide limits of gravity and distillation products.

Mid-Continental Field (28). — This region underlies a portion of southeastern Kansas and northeastern Oklahoma, and extends roughly from Paola, Kansas, to Muskogee, Oklahoma. The Pennsylvanian rocks which outcrop in this area dip westward from 20 to 30 feet per mile in Kansas and double that in Oklahoma. At the base are the Cherokee shales (400 to 500 feet thick) which are overlain by the Fort Scott limestone and shale and rest unconformably on the Mississippian Limestone.

All the shales, especially the Cherokee, carry sandstone beds, which yield oil and gas, but the most important ones are at the base of the Cherokee, while another one is near the top, and still another in the Fort Scott limestone. The Mississippian carries but little oil, except near Muskogee, where an important sand was struck at a lower geological horizon than oil or gas had previously been found in this region. Another large pool, the Glen, has been pierced near Tulsa, Oklahoma. Southwest of this point the structure is much complicated by folding and faulting.

The oil and gas are struck in different parts of the region at depths ranging from 350 (Coffeyville, Kansas) to 1600 feet (Bartlesville, Oklahoma).

Most of the Kansas oils are asphaltic, but in Oklahoma oils of both asphaltic and paraffin types are found, those found near Muskogee resembling the Pennsylvania oils.

This region has become a large producer, but the output is supplied mainly by the Oklahoma field, while the Kansas one is on the decline.

California (15–20). — The oil fields of California (Fig. 29) lie mainly south of the latitude of San Francisco and on either side of the Central Valley of the State, either in the Coast Range or on the Pacific front. The productive fields include the Kern River, Coalinga, Santa Maria, McKittrick, Midway, Sunset, Bakersfield, Los Angeles, Puente Hills, and Summerland. The sections in the different fields include a great thickness of strata, ranging in some cases from Jurassic to Quaternary, the oil occurring mainly in the Tertiary, sandstones, conglomerates, and shales. In one district (Placerita Cañon, Puente Hills), it is found in a crystalline schist, overlying granite (17).

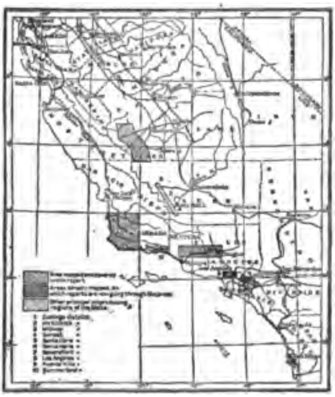

FIG. 29. — Index map of a portion of southern California, showing location of oil fields. (*After Arnold, U. S. Geol. Surv., Bull.* 357.)

The productive areas show a close association with anticlines; indeed, strong folding and even faulting are not uncommon, the latter having often caused interstitial spaces in which the oil could accumulate. Owing to the fracturing of the rocks incident to strong folding and faulting, oil seepages are common in some districts.

Eldridge has suggested that "since the stratigraphic and structural conditions under which oil occurs in the known fields are many times repeated elsewhere, in the Coast Range and territory contiguous thereto," there is hope for extending the oil region. Reference to two fields will serve to indicate the mode of concurrence.

In the Kern River field, which is the most important, the well records indicate a great body of Miocene (Tertiary) sands and clays in which the general westerly dip away from the Sierra granites has been locally interrupted by anticlines, on the flanks of which the oil has been found.

The oil occurs in sands interbedded with the clays which underlie one heavy clay bed and overlie another. The thickness of the oil-bearing sands may vary from 200 or 300 to 400 or 500 feet.

The Santa Maria field comprises the Santa Maria, Lompoc, and Arroyo Grande fields, in northern Santa Barbara and southern San Luis Obispo County. The formations involved range from Jurassic to Quaternary, involving beds of shale, stone, sandstone, diatomaceous earth, volcanic ash, and in the Jurassic even schist, jasper, and serpentine.

There are two structural systems in the district, (1) in northeast part, trending northwest and southeast, and (2) in southern part trending east and west. Faults are rare, but the productive territory is gently folded. Most of the wells are located along or near anticlines, and range in depth from 1500 to over 4000 feet. In the Santa Maria and Lompoc fields the oil is obtained from zones of fractured shale, or sandy layers in the lower portion of Monterey (Middle Miocene), and has an average gravity of 25° B. In the Arroyo Grande area it comes from sandstones at base of the Fernando, and has a gravity of 14° B.

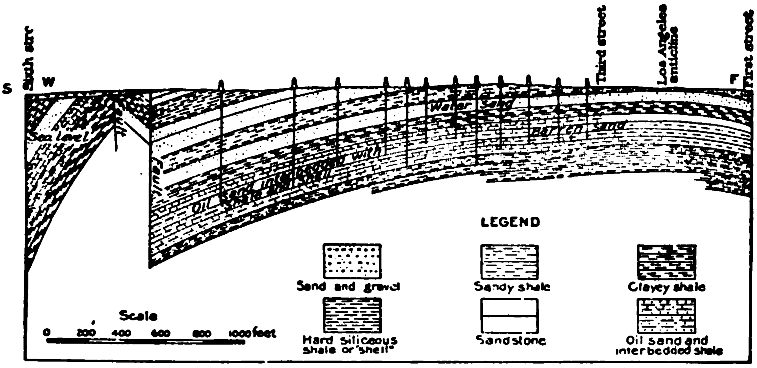

FIG. 30. — North-south section, showing structure of western field of Los Angeles district. (*After Eldridge and Arnold, U. S. Geol. Surv., Bull.* 309.)

Although the Kern River field leads in point of production, the Santa Maria leads in the production per well, and supplies most of the oil exported, its situation giving it command of the coast trade from Alaska to Chile, as well as foreign trade with Japan and Hawaii.

The Summerland field is of interest, for the reason that Arnold believes the oil to have been derived from diatoms (19), and other organisms found in the Monterey shale. It has subsequently migrated upward into the overlying Fernando, and to some extent Pleistocene formations, urged along probably by gas or hydrostatic pressure. A similar origin is also ascribed to the oil in the Coalinga district.

The California oils are generally characterized by much asphalt and little or no paraffin, although in recent years there has been a considerable yield of lighter grade oils from the Santa Maria and Monterey districts. Since these are well adapted to refining, they will probably be in strong demand.

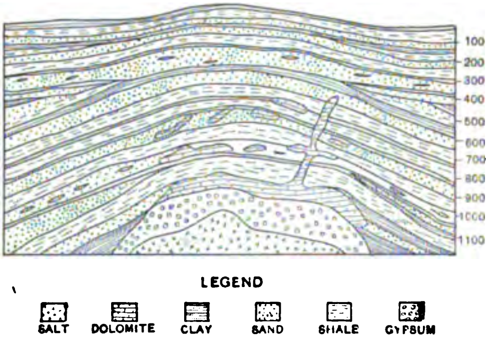

FIG. 31. — Section of Spindle Top oil field near Beaumont, Tex. (*After Fenneman, Min. Mag., XI.*)

Texas-Louisiana Oil Fields (34, 35, 49–51). — This includes a series of small scattered fields lying mostly in the coastal plain region of Texas and Louisiana (Pl. VI). Underlying the coastal plain there is a series of Quaternary, Tertiary, and Cretaceous clays, sands, and gravels, with occasional limestones, having in general a gentle southeastern dip, interrupted by low

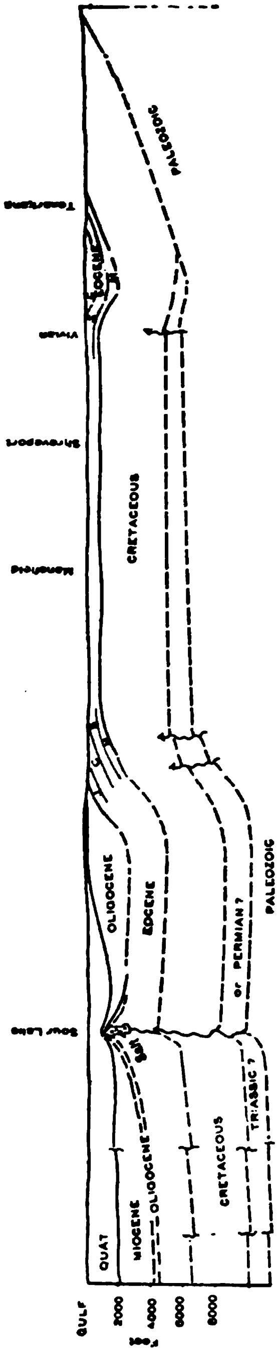

FIG. 32. — Generalized section from Paleozoic outcrop in Arkansas through Caddo oil field, and Sour Lake to Galveston, Tex. (*After Harris, La. Geol. Surv., Bull. 9.*)

domes, which, in parts of Louisiana at least, appear to be due to the upthrust caused by growth of salt and gypsum masses.

Under these domes, or mounds, and underlying the sediments mentioned above, there are usually found deposits of marly or crystalline limestone (often dolomitic), sulphur, gypsum, and rock salt, which in most cases are at considerable depth, but occasionally lie at or near the surface. Thus at Avery Island, Louisiana, the heavy deposit of rock salt comes within 15 feet of the surface, but at Spindle Top, Texas, the limestone is 800 or 900 feet deep.

The oil is most frequently found in or near the limestones.

The oil pools are of small size, and that discovered at Beaumont, Texas, may serve as a type of many. This pool, which covers an area of about 200 acres (Pl. IX), was discovered in 1901, and within a year and a half 280 successful wells had been drilled. The oil rock, which lies from 900 to 1000 feet below the surface, is a very porous, crystalline, dolomitic limestone, and the cap rock is clay. The occurrence of gypsum and salt underlying the oil rock in some of the wells is unique (Fig. 31). Many of the wells in this pool were gushers, but so great was the drain on this field that by the end of the first year after its discovery the pressure was considerably reduced, and in 1903 many of the wells had practically ceased producing, while others were yielding

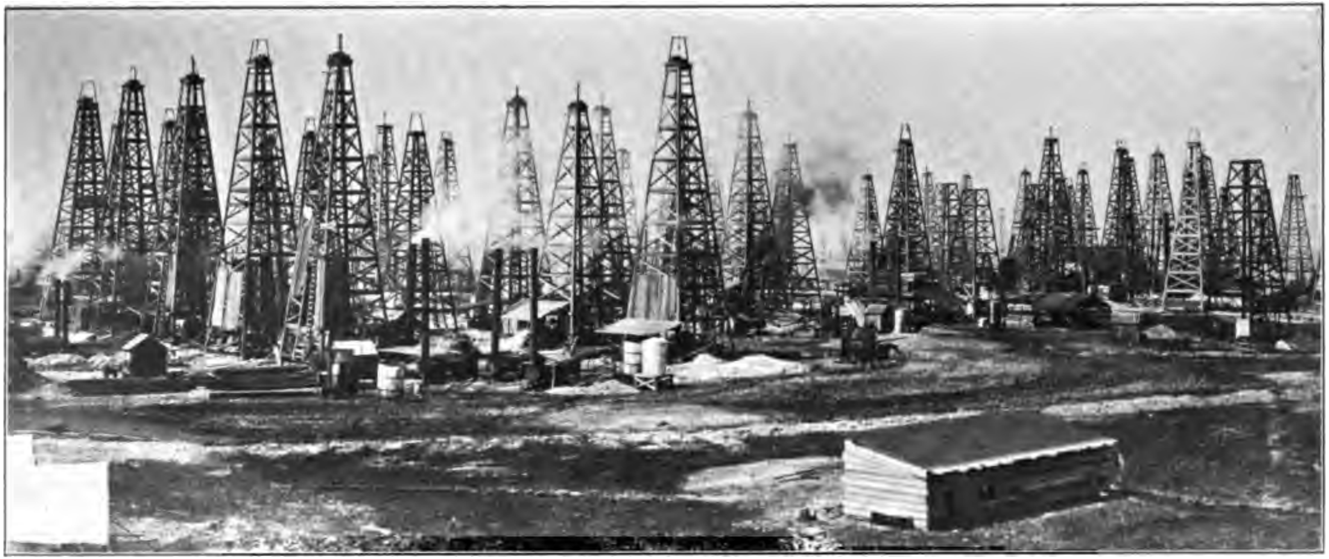

Plate IX. — General view of Spindle Top oil field, Beaumont, Tex. (*Photo. by Troost.*)

a mixture of salt water and oil. The production, however, is still considerable, although the supply is no doubt exhaustible. The coastal-plain oils have an asphaltic base, or are "heavy," and at times contain considerable sulphur.

In 1903 many wells were being developed in the Sour Lake district about 20 miles northwest of Beaumont. The oil is heavy like that of Beaumont, but runs lower in sulphur. In Louisiana active drilling operations have been carried on in the region around Jennings, and one well yielded 20,000 barrels per day while it was gushing. The oil resembles that of Beaumont.

The belt of Cretaceous rocks of central Texas has yielded both oil and gas at several localities, but the only important one is at Corsicana, where both a light and heavy oil have been found in sands interbedded with dense clay shales. The two kinds of oil occur at different horizons.

In northwestern Louisiana, both oil and gas are found in the more or less consolidated Cretaceous rocks, which underlie the Tertiary and Quaternary. Here the Cretaceous rocks which dip to the southward show a domelike uplift of considerable dimensions, which brings them within 700 feet of the surface. This includes the Caddo field, and although the oil and gas occur separately or together at four horizons, viz. the Nacatoch, Austin, Eagle Ford, and Woodbine, of the Upper Cretaceous, most of the gas is obtained from the first or upper, and the oil from the fourth or lower division. The main oil sand is about 2200 feet deep. The oil from this field is light, similar to that of the Appalachian region, and thus differs strongly from the Beaumont and Jennings oils (Harris).

Most of the oils of the Gulf region contain considerable quantities of sulphur, largely in the form of hydrogen sulphide, and therefore easily removed by steam before refining, or for use as fuel. They make a good fuel oil, which because of the location of the field can be easily exported, but they also yield a good grade of lubricating oil. Moreover, the gasolene derived from them is acceptable as a substitute for turpentine.

The Corsicana and Caddo field oils are lighter and run lower in sulphur.

Colorado. — Florence (21) and Boulder (22) are the two important oil-producing localities. At the former the oil is found in beds of Cretaceous age, at depths of from 1000 to 2000 feet, and, unlike many occurrences, appears to have accumulated in fissures, although the rocks of the region as a whole form a syncline.

At Boulder, the oil is found associated with broad low anticlines in sandstones and shales of the Pierre (Cretaceous) formation, and is now being obtained at depths ranging from 2100 to 2350 feet.[1] The oil does not vary much in quality.

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[1] R. D. George, private communication.

Wyoming (58–63). — This state contains a number of oil and some gas districts (Fig. 33), most of which are but slightly developed,

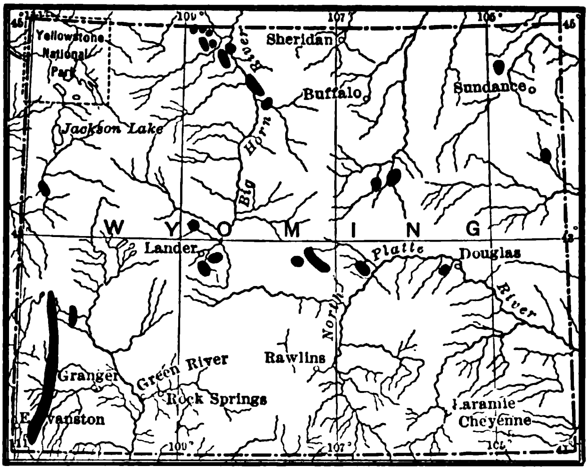

FIG. 33. — Map of Wyoming, showing approximately the areas underlain by oil and gas. (*After Day.*)

and the geology of them imperfectly known. The oil-bearing formations range in age from Carboniferous or Permian to Tertiary (62), but the Cretaceous contains the bulk of the oil thus far discovered.

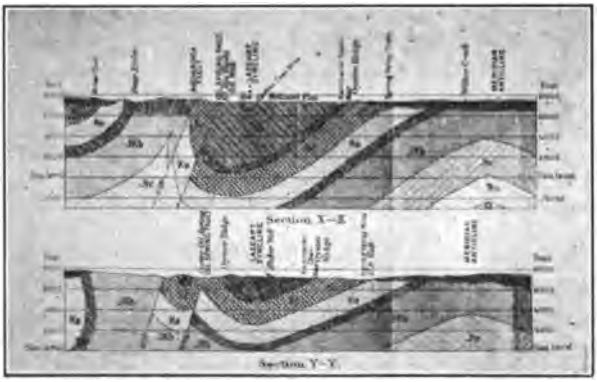

FIG. 34. — Section across portion of oil district of southwestern Wyoming. (*After Veatch, U. S. Geol. Surv., Prof. Pap. 56.*)

Many of the occurrences appear to be associated with anticlines (62), but, in one field (Spring Valley, Uinta County) at least (63), the oil occurs in a synclinal basin (Fig. 34), whose bounding fault on the northwest seems to have permitted somewhat abundant seepage.

The oils vary in their gravity, but, according to published data, are mainly of medium gravity. Those obtained near Evanston are refined (63).

Uinta and Converse counties are said to be the most important producers, but still the entire output of the state is small.

Alaska (14). — Oil has thus far been found in Alaska at only four localities, at which the indications were sufficient to warrant drilling. Wells have been driven at three, and disclosed the presence of oil similar to that of Pennsylvania. All of the fields lie in the Pacific coast region, but none have been extensively developed, as the low price of imported oil and high cost of drilling in Alaska have discouraged attempts towards development.

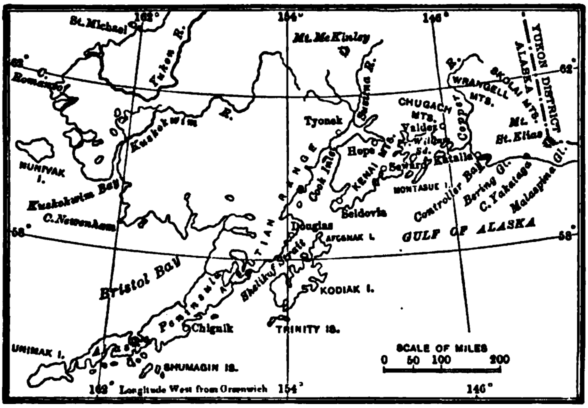

FIG. 35. — Map of Alaska, showing areas in which oil or gas are known to occur. (*After Day.*)

In the Katalla field, located near the mouth of the Copper River, the oil is found in complexly folded and faulted Tertiary shales and sandstones. At Cook Inlet, folded and faulted Jurassic shales and sandstones form the petroliferous horizon. At Cold Bay, where seepages are found as in the other fields, the structural conditions and age of the oil-bearing strata are similar to those at Cook Inlet. Seepages are found in Tertiary rocks near Cape Yakataga, but no wells have been drilled.

Summary. — The following table summarizes very briefly the mode of occurrence in the several fields: —

Summary of Oil Occurrence in the Principal Fields

Field	Structure	Geologic Age	Kind of Rock	Kind of Oil
Appalachian.	Geosyncline with subordinate anticlines.	Ordovician to Carboniferous.	Mostly sandstone.	Paraffin base.
Lima-Indiana.	Anticlines.	Ordovician.	Mostly limestone.	Paraffin base. Sulphur.
Illinois.	Low anticlines (?)	Carboniferous.	Sandstones.	Paraffin and mixed oils.
Michigan.	Probably anticlines.	Silurian.	Sandstones.	Paraffin base.
Mid-Continental.	Westerly dip, with some anticlines.	Carboniferous.	Shales, sandstones mostly.	Both paraffinic and asphaltic.
Wyoming.	Usually folded.	Carboniferous to Tertiary.	Mostly sandstone.	Paraffinic and asphaltic.
Colorado.	Folded.	Cretaceous.	Sandstone and shale.	Paraffinic.
Gulf Coast.	Domes.	Tertiary and Cretaceous.	Dolomite and sandstone.	Mainly asphaltic, sometimes high sulphur.
California.	Folded and faulted.	Tertiary.	Sandstones, shales, conglomerates.	Mainly asphaltic.
Alaska.	Folded and faulted.	Jurassic to Tertiary.	Sandstones and shales.	Paraffin.

Distribution of Natural Gas in the United States. — The distribution of gas is practically coextensive with that of petroleum, and most oil wells yield some gas; but the regions from which supplies are obtained and utilized are fewer than those of petroleum.

Day (53) gives the following estimate of the area in square miles of gas pools in the several fields.

Appalachian	Kentucky	290	
	New York	550	
	Ohio	110	
	Pennsylvania	2730	
	West Virginia	1000	4680
Ohio-Indiana	Indiana	2460	
	Ohio	165	2625
Illinois			50
Michigan			40
Mid-Continental	Oklahoma	1000	
	Missouri	70	
	Kansas	550	1620
Colorado			80
Wyoming			120
California			310
Texas-Louisiana			240
Others			290
			10,055

The most important producing states at the present time are Pennsylvania (78), Ohio (77), West Virginia (56), Kansas (70), New York (74), and Indiana (68).

New York (74, 75). — Gas is found in several formations, including the Medina (Silurian) and Oswego sandstones (Silurian), Utica shale (Ordovician), and Potsdam (Cambrian) sandstone, but the main supply is distributed through the Devonian sandstones of southwestern New York. A large field in Erie County obtains its supply from the Medina sandstone, some of the wells having yielded as high as 1,000,000 cubic feet daily. In Onondaga County gas is found in the Trenton limestone (Ordovician).

Pennsylvania. — Gas is obtained from the same formations that carry the oil. The Bradford district was the first developed, and formerly yielded gas of high pressure. Much has, even recently, been obtained from McKean, Elk, and Warren counties. Extensive deposits were also found about Pittsburg, and later to the south of it. Greene and Washington counties now produce important supplies from a pool whose length is about 25 miles and width 3 to 4 miles, with pressure ranging from 800 to 1000 pounds. Although in recent years several new gas-bearing sands have been discovered in southwestern Pennsylvania, the enormous demand for the gas threatens exhaustion of the available supply at no very distant date.

West Virginia (see Petroleum references). — This state is now the leading producer of natural gas in the United States, and is even now an important source of supply for both Ohio and Pennsylvania, whose gas supply is slowly falling off. The main supply is obtained from the Gordon and Fifth sands of the Catskill (Devonian) formation, this being a higher horizon than that yielding the gas in the Bradford district of Pennsylvania. Immense quantities are obtained from the fields of Wetzel and Tyler counties, the wells being from 2700 to 3200 feet deep. Pipe lines are now run from this district to Pittsburg, and a line has been laid from Tyler County to Cleveland, Ohio. Unfortunately, by allowing it to escape with the petroleum, many thousand cubic feet of gas have been wasted in this state.

Ohio (76–77). — The Trenton (Ordovician) limestone, which formerly supplied large quantities of natural gas, is now so nearly exhausted that little gas is obtained except by pumping. Some gas is obtained from the Clinton (Silurian) sandstone of central and eastern Ohio, and small amounts from the Corniferous (Devonian) limestone; but many towns in this state are now supplied by the West Virginia fields.

Indiana (67, 68). — The gas fields of this state, covering about 2500 square miles, were formerly among the most important in the country, the gas being obtained from the Trenton limestone. The supply is, however, rapidly giving out, and its complete exhaustion is probable at no very distant date.

Kansas (70). — Southeastern Kansas and also northern Oklahoma are underlain by what is probably an extensive sandstone gas field. The supply comes from the Cherokee (Carboniferous) shale, and is now much used as a source of fuel in the local metallurgical and manufacturing industries.

Some gas is obtained from eastern Kentucky. Scattered pockets of high-pressure gas have also been found at several localities in Texas, Louisiana (73), and also in California.

Uses of Petroleum. — The three most important uses are for light, heat, and lubrication; but the various distillates have special uses. Rhigolene is used as a local anæsthetic, gasoline is used as fuel, and naphtha as a solvent for resins in making varnish and in oilcloth manufacture, while benzine is of value for cleaning and as a substitute for and an adulterant of turpentine. Astral oil and mineral sperm oil are special grades of illuminating oil with high flashing points. Crude petroleum is now much used for fuel purposes in engines, as along the Pacific coast and in the southwest, where good coal is so scarce that many of the locomotives are run by the use of crude oil.

The paraffin residue is placed on the market for medicinal purposes under the name of vaseline, petroleum ointment, and cosmoline. It is also used as an adulterant of candy and for electrical insulation.

Uses of Natural Gas. — Natural gas is widely employed as a fuel in factories, metallurgical establishments, glass works, cement plants, etc. For domestic purposes, such as heating, cooking, and lighting, it is also widely used. Its cheapness, cleanliness, and high calorific power, and the ease with which it can be used, have been important factors in insuring its widespread selection for the above purposes. Some is used in the manufacture of lampblack.

SOLID AND SEMI-SOLID BITUMENS

Under this heading are included (1) bitumens of a more or less solid character which are found filling fissures in the rocks, or sometimes occupying basin-shaped depressions on the surface, and (2) bitumen of viscous character, or *maltha*, which is found oozing from fissures or pores of the rocks and sometimes collecting in pools on the surface.

Both of these are usually of rather high purity, and those belonging to the first-named group may have a rather wide geologic and geographic (Fig. 36) range.

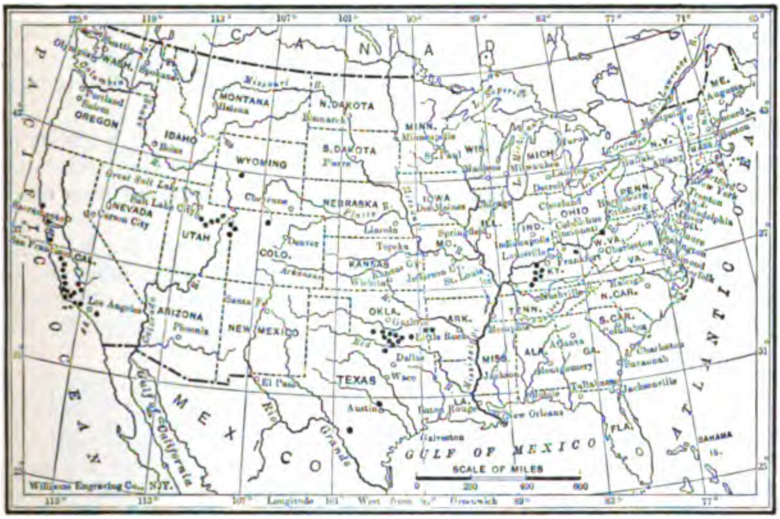

FIG. 36. — Map of asphalt and bituminous rock deposits of the United States. (*After Eldridge, U. S. Geol. Surv., 22d Ann. Rept., IX.*)

Those of the first group were termed *asphaltites* by Eldridge, but since they are not all true asphalts, it seems best perhaps to avoid this term. They are most commonly found filling fissures, usually in sedimentary rocks,[1] and might perhaps be termed *vein bitumens.*

Vein Bitumens. — There are several varieties of these, all black or dark brown in color, commonly with a pitchy odor, burning readily with a smoky flame, and insoluble in water, but soluble to a varying degree in ether, oil of turpentine, and naphtha. Their specific gravity ranges from 1 to 1.1. They are closely related chemically and in their mode of occurrence, but differ somewhat in their behavior toward solvents, as well as in their fusibility, so that their identification is often somewhat uncertain. The most important varieties are described below.

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[1] The anthraxolite of Ontario occurs in slate, and an asphalt vein in quartz-porphyry has been described from near Heidelberg, Germany. (Geol. Zentralbl., XIII: 547, 1909.)

Albertite (91). A black bitumen with a brilliant luster and conchoidal fracture, a hardness of 1 to 2, and specific gravity 1.097. It is barely soluble in alcohol, and dissolves to the extent of 4 per cent in ether and 30 per cent in oil of turpentine.

Some American occurrences of vein bitumens are thought to belong here, but the most important occurrence is at Albert Mines, New Brunswick (91) where a vein of albertite is found in the Upper Devonian shales. The vein had a length of about half a mile and was followed down its steep dip to a depth of 1500 feet. Its thickness varied from 15 feet to zero, and branch veinlets ran off into the wall rock. It was worked for thirty years and proved to be one of the most profitable mineral industries of New Brunswick.

Anthraxolite (93) is a coaly, lustrous, black mineral, with a hardness of 3 to 4, and specific gravity of 1.965. It is found at Sudbury, Ontario, forming veins in a black fissile slate, but has also been described from other localities.

Ozokerite (98, 106), also termed *mineral wax* or *native paraffin*, is a wax-like hydrocarbon, yellow brown to green, translucent when pure, and of greasy feel. Its specific gravity ranges from .845 to .97. It is easily soluble in petroleum, benzine, benzole, turpentine, and carbon disulphide, but more difficultly so in ether and ethyl alcohol.

It is known to occur in Utah (106) where the material is found filling fissures in zones of crushed Tertiary shales, sandstones, and limestones, near Midway, Soldiers Summit, and Coulters station on the Rio Grande and Western Railway. The conditions are not regarded as very favorable for working. The most important deposit of Ozokerite is in Galicia. There it is found forming veins from a few millimeters up to several feet in thickness, in much-disturbed Miocene shales and sandstones.

Grahamite (97, 105, 108). — This has a hardness of 2, and a specific gravity of 1.145. It is pitch-black, slightly soluble in alcohol, partly so in ether, petroleum, and benzole, but almost completely in turpentine. Carbon disulphide and chloroform dissolve it completely.

Grahamite was originally found in the Carboniferous sandstones of Ritchie County, W. Va.[1] There it occurred in a deep vertical fissure 1 to 5 feet wide at the surface, and nearly a mile in length, which was opened up at right angles to the direction of an anticlinal fold (Fig. 37). Through this the oil escaped upwards from an oil pool, known to occur below, and was oxidized to grahamite. The vein has long since been worked out.

Deposits of grahamite are also known in southeastern Oklahoma, where the material occurs in steeply pitching veins, in sandstones, and shales.

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[1] White, Bull. Geol. Soc. Amer., X : 277, 1899.

The wall rocks which are of Ordovician to Carboniferous age, vary from flat to highly folded, and the grahamite shows corresponding fluctuations in composition which are due no doubt to differences in the degree of metamorphism which the rocks have undergone. The veins are uncertain in extent, and with two exceptions have not warranted extensive development.

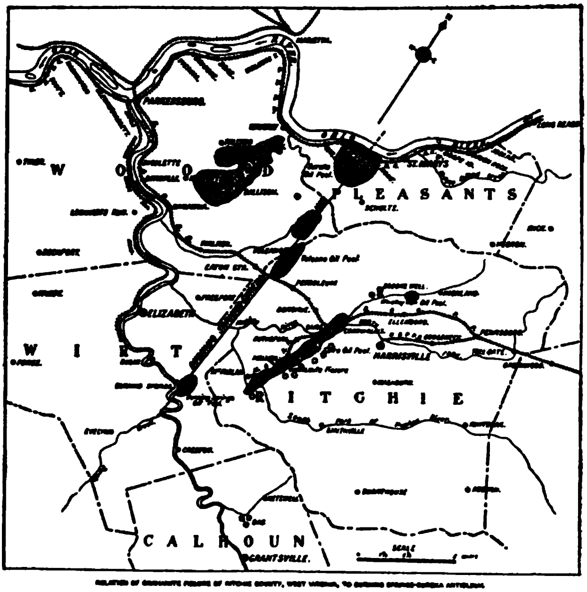

Fig. 37. — Map showing relation of grahamite fissure to anticlinal fold, in Ritchie County, W. Va. (*After White, Bull. Geol. Soc. Amer., X.*)

Other deposits are located in western Arkansas but the material is badly crushed and more highly metamorphosed (105).

Proximate Analyses of Oklahoma and Arkansas Bitumen

	I	II	III
Moisture	.25	.09	2.51
Volatile bitumen	43.33	23.06	17.78
Fixed Carbon	55.97	75.90	79.15
Ash	1.45	.95	.56
Sulphur	1.47	1.69	1.38

I. Impson Valley grahamite. II. Black Fork Mountain vein bitumen. III. Fourche Mountain vein bitumen. Nos. II and III occur in the more highly folded rocks, and show effects of metamorphism.

Wurtzilite (97) is a bitumen related possibly to gilsonite, but distinguished from it by its behavior towards solvents, and by its elastic and sectile properties. It has a hardness of 2–3, and specific gravity of 1.03; is black, with pitchy luster, and petroleum-like odor. *Tabbyite* is regarded by some as similar. Wurtzilite is found filling fissures in Tertiary calcareous shales and limestones in the western part of the Uinta Basin, Utah. It has been but little mined.

Lake Asphalt (103) is not found in the United States, but occurs in the famous pitch lake on the island of Trinidad, off the coast of Venezuela.

The deposit Pl. X and Pl. XI, Fig. 1, appears to occupy a basin-shaped depression of about 100 acres and nearly circular outline (Fig. 38) lying 138 feet above the sea level. The material evidently arises from some source below, as excavations made in the pitch fill up again in a short time. Two forms of the asphalt are recognized, viz. the lake pitch and the land pitch, the latter being asphalt which has overflowed from the lake at a low point on its rim, and run down to the sea. Up to the present time about 3 million short tons of asphalt have been exported from the island.

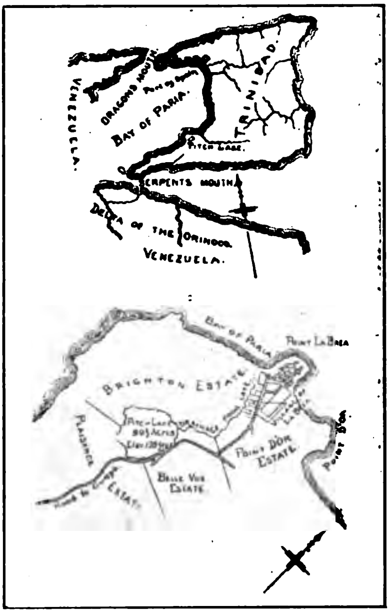

FIG. 38. — Plan of Trinidad pitch lake. (*After Peckham.*)

Manjak (100*a*) is the name applied to a bitumen resembling Uintaite, found on the island of Barbados. It is a hydrocarbon of high purity, black color, brilliant luster, and conchoidal fracture.

The Manjak is found in veins cutting obliquely across the upper strata of the oil series (Oligocene) and disseminated through the clays. The largest vein is over 27 feet thick and often shows unusually rich pockets. The close association of this asphalt with the petroleum has led most geologists to assume its derivation from the latter.

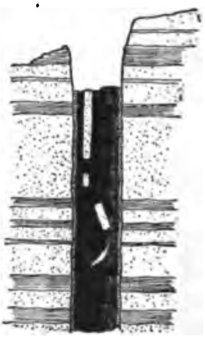

FIG. 39. — Section of Gilsonite vein, Utah. (*After Eldridge, U. S. Geol. Surv., 17th Ann. Rept., I*).

Uintaite, or *Gilsonite* (97), is a black, brilliant bitumen, with conchoidal fracture, hardness 2 to 2.5, and specific gravity of 1.065 to 1.07. It is partly soluble in alcohol (45.4 per cent), more so in ether, and completely in chloroform and warm oil of turpentine. It is found filling a series of fissures (Figs. 39 and 40), termed veins, in the Bridger beds of the Tertiary of Uintah and Wasatch counties, northeastern Utah, and, to a less extent, in western Colorado. The veins strike usually northeast-southwest, and vary

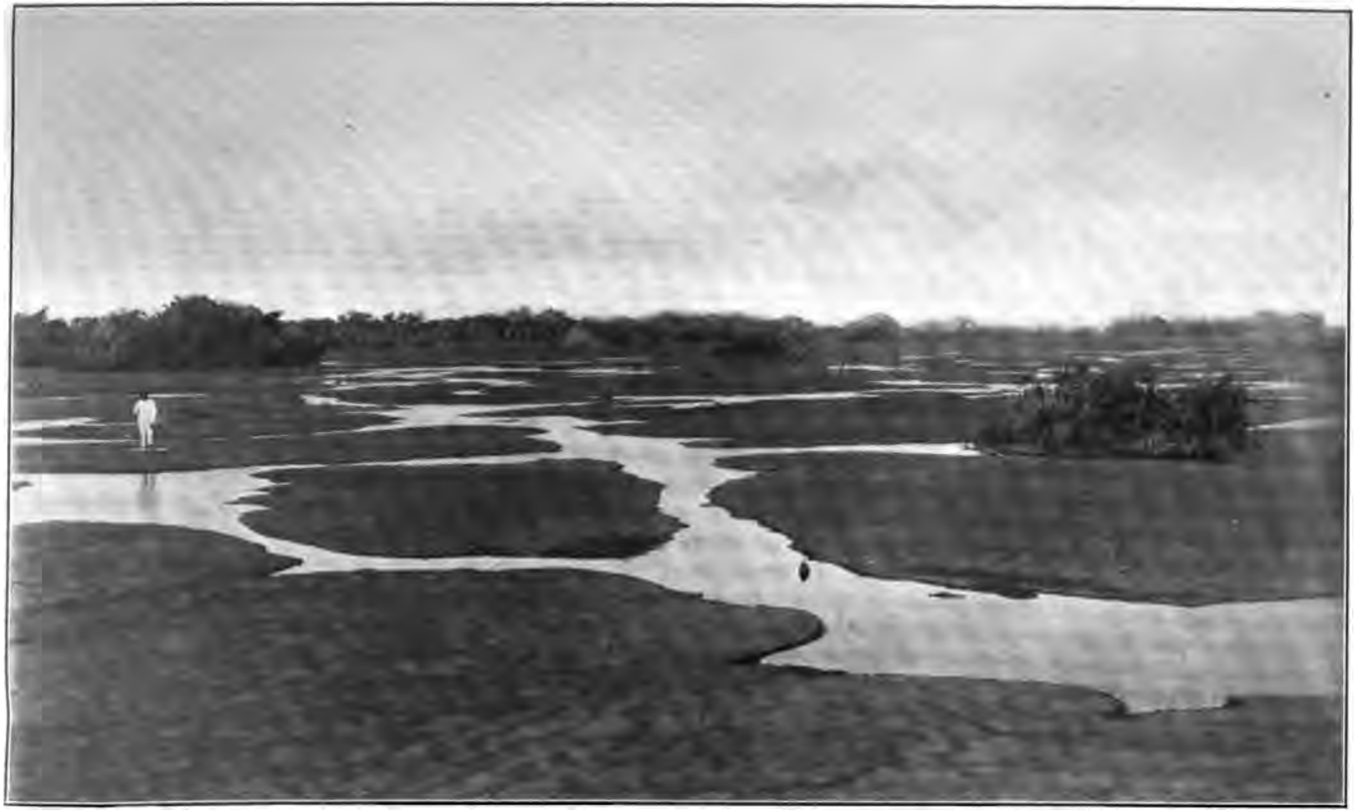

Plate X. — General view of Trinidad asphalt lake. The clumps of bushes in center are "floating" islands. (*Photo. loaned by Barber Asphalt Company.*)

greatly in width, extremes of 18 feet being reported. They are traceable for long distances, but their vertical depth appears to be unknown.

Maltha. — This is usually found issuing from crevices or pores of the rocks, the latter being sometimes of bituminous character. It can also be extracted from bituminous rock and asphaltic oils.

Maltha is not known to occur in large deposits in the United States, although it is somewhat widely distributed in some of the California oil fields, where the petroleum exudes from the rocks, and on exposure to the air becomes converted into maltha by the loss of its more volatile constituents. In the Santa Barbara (18) and Kern County oil fields it is found in fissures of limited extent. Its occurrence has also been noted in Oklahoma.

Oil asphalt is obtained from the distillation of certain asphaltic oils of California and Texas, and some of these are said to contain over 35 per cent of it.[1]

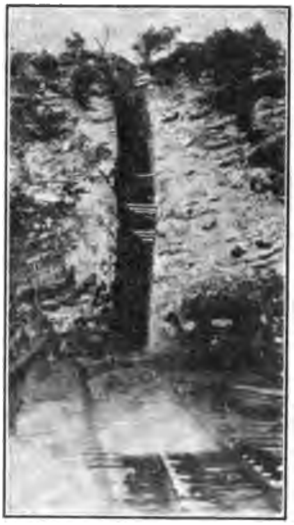

FIG. 40. — Gilsonite mine at Dragon, Utah. The cut represents position of vein. (*Rept. of Coal Mine Inspector, Utah,* 1905–1906.)

ELEMENTARY ANALYSES OF BITUMENS AND MALTHA

	1	2	3	4	5	6	7	8	9	10	11
	OZOKERITE, UTAH	MALTHA, CARPINTERIA, CAL.	IMPSOMITE, IND. TY.	GRAHAMITE, W. VA.	GRAHAMITE, W. VA.	ALBERTITE, NOVA SCOTIA	ALBERTITE, NOVA SCOTIA	GILSONITE, UTAH	GILSONITE, UTAH	WURTZILITE, UTAH	LAKE PITCH, TRINIDAD
C . .	85.25	85.72	86.57	76.45	59.20	86.04	85.53	88.30	89.28	80.00	83.68
H . .	15.09	11.83	7.26	7.83	5.77	8.96	13.20	9.96	8.66	12.23	10.84
N . .	—	1.21	1.48	tr	1.01	2.93	.42	.32	.79	1.78	.45
O . .	—	—	2.00	13.46	14.68	1.97					
S . .	—	1.32	1.38	tr	—	tr	1.20	1.32	1.79	5.83	5.10
Ash .	—	—	1.31	.10	19.34	.10	—	.10	—	—	—
Moisture	—	—	—	—	—	—	—	—	—	—	—

1, 9, 10, 11. Richardson, "Nature and Origin of Asphalt," 1898. 2. Munic. Eng. Mag. June–August, 1897. 3. Amer. Jour. Sci., Sept. 1899, p. 221. 4. Wurtz, analyst, Amer. Jour. Sci., iii, VI: 415, 1873. 5. Hite, analyst, Geol. Soc. Amer., Bull. X: 283, 1899. A proximate analysis made on another sample gave 1.13 sulphur. 6. Trans. Amer. Philos. Soc., Phila.: 853, 1852. 7. Richardson, Modern Asphalt Pavement: 209, 1905. 8. Jour. Frankl. Inst., CXL, No. 837, Sept. 1895.

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[1] Taff, U. S. Geol. Surv., Min. Res., 1908.

BITUMINOUS ROCKS

Under this heading are included consolidated and unconsolidated rocks, whose pores are more or less completely filled with bituminous matter, often of asphaltic character (97).

They are commonly classified according to the character of the containing rock as bituminous sands or sandstones, bituminous limestones, shales, or schists.

Bituminous rocks vary not only in their richness, but also in their value for paving purposes, for while in some the bituminous matter is purely asphalt proper, in others it may consist wholly or in part of maltha or some liquid bitumen, which may interfere with its use for paving purposes.

Deposits of bituminous rock are more widely distributed than the vein bitumens, being found in several geological horizons, and are worked in Kentucky (97), Oklahoma (97), and California (97).

In California deposits of asphaltic shale and sandstone are not of rare occurrence in the oil regions from Santa Cruz southward. The bituminous sandstone quarried near the above named place (Pl. XI, Fig. 2) is of blackish or brownish-black color, weathering to gray, and occurs beneath the Monterey shales; it sometimes rests directly on the granites. The bitumen impregnates the heavy-bedded sandstone immediately under the shale, and also the sand that fills cracks which extend up into the shale. These cracks, which vary in width from very minute size up to 25 or 30 feet, are sometimes traceable for several hundred feet, being at times of value as guides in finding the main bed.

Analyses of Bituminous Rocks

Locality	Moisture	Soluble in CS_2	$CaCO_3$	$MgCO_3$	Sand or Clay
California	2.50	20.20	3.00	—	74.00
Kentucky	—	5.76	—	—	94.22
Seyssel, France . . .	—	8.15	91.70	—	—
Limmer, Germany . .	—	18.26	56.50	27.01	4.98

OIL SHALES

Shale containing sufficient petroleum to permit its extraction by a process of distillation is known as *torbanite* or *kerosene shale* (80–84). Such shales are found in the Carboniferous of New South Wales,

PLATE XI

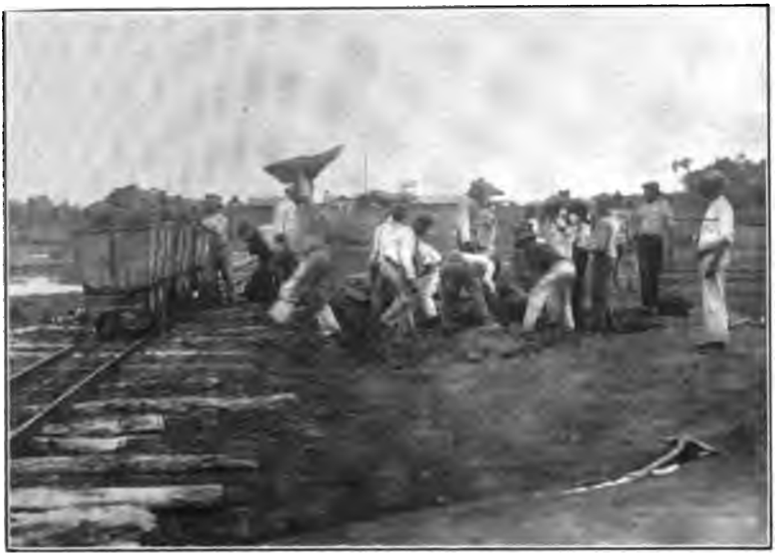

FIG. 1. — View of portion of Trinidad asphalt lake, showing digging operations. (*Photo. loaned by Barber Asphalt Company.*)

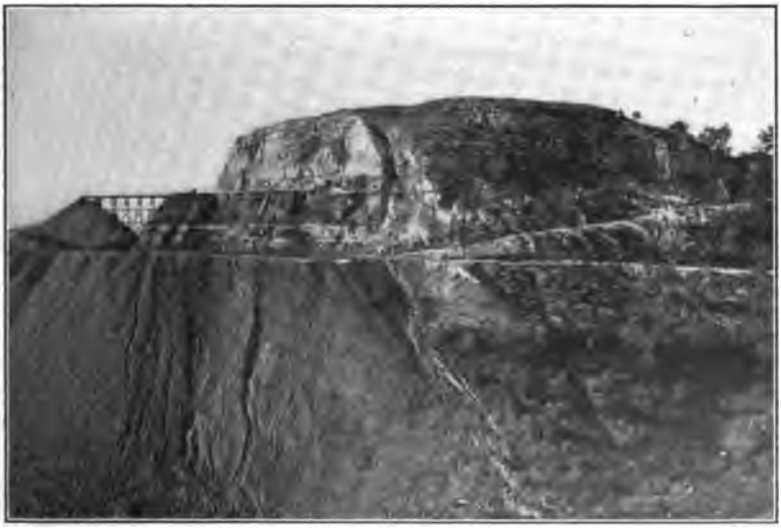

FIG. 2. — Quarry of bituminous sandstone, Santa Cruz, Cal. (*After Eldridge, U. S. Geol. Surv., 22d Ann. Rept., I.*)

Australia, New Zealand, and Scotland, and in the Cretaceous of Brazil. Those in New South Wales are being worked, and in Scotland the industry has thrived under careful management for a number of years.

In Albert and Westmoreland Counties of New Brunswick, Canada, there is a considerable area underlain by black, brown, and gray shales of Upper Devonian age, which contain a number of bands of oil shale. Tests of some of these have yielded 63 gallons of crude oil per ton, and in 1909 investigations were under way looking towards their development.

Oil shales are but little known in the United States, although they no doubt exist.

The following analysis indicates the composition of an oil shale:

	Moisture	Volatile Hydrocarbon	Fixed Carbon	Ash	Sulphur
Rich shale, Joadja, N.S.W. .	.16	89.59	5.27	4.96	.384

The oil can be obtained by distillation in retorts; but in view of the large available supplies of petroleum, obtainable in many parts of the world, the material at present has but little commercial value.

The crude oil extracted by distillation from a ton of Scotch shale (Steuart) varies from 16 to 35 gallons and the ammonium sulphate from 30–70 pounds. The refined products of the crude oil are spirit of naphtha, 4 per cent; burning oil, 33 per cent; gas oil, 7 per cent; lubricating oil, 20 per cent; solid paraffin, 10–12 per cent.

Origin of Solid Bitumens and Bituminous Rocks. — A study of the deposits leads to the conclusion that these solid bituminous compounds have been derived from petroleum (87, 88, 89, 90), for the following reasons: In the vein deposits the solid bitumens are often associated with petroleum springs, or with fissures leading down to or toward petroleum-bearing strata. In some cases the material not only fills such a fissure, but impregnates the wall rock to a distance of a foot or more on either side of the vein, indicating that the material came up through the fissure in a liquid condition, filling it, and even penetrating the wall rock.

The bitumen in bituminous rocks may either have originated from organic remains within the rock itself or have seeped into it from some neighboring pool. In either case the material seems originally to have been liquid petroleum, some of which later solidified.

Uses of Asphalts. — Trinidad asphalt mixed with powdered rock and tar is much in use for pavements, and the bituminous rocks are employed for similar purposes. Ozokerite, known as Ceresin in its purified form, is used in the manufacture of candles, ointments, powders, as an adulterant of beeswax, and for bottles to hold hydrofluoric acid.

The most important use of Uintaite and Manjak is for making low grade and dipping varnishes, such as are used for iron work and baking Japans. Other uses to which the Uintaite at least has been put are for preventing electrolytic action on iron plates of ship bottoms, coating masonry, acid-proof lining for chemical tanks, roofing pitch, insulating electric wires, as a substitute for rubber in common garden hose, and as a binder pitch in making coal briquettes.

Production of Petroleum and Natural Gas. — Petroleum has long been known in many parts of the world because of its presence in bituminous springs or as a floating scum on the surface of pools. It was used at an early date on the walls of Babylon and Nineveh, and was obtained by the Romans from Sicily for use in their lamps.

In the United States petroleum was mentioned by French missionaries even in 1635, and the early Pennsylvania settlers obtained small quantities by scooping out the oil from dug wells. Its discovery at a greater depth on the western slope of the Alleghanies was made during the drilling of brine wells; but its early use was chiefly a medicinal one until 1863, when attempts were made to purify it for use as a lubricant and illuminant. The beginning of the oil industry is usually considered to date from the sinking of a successful well by Colonel Drake on Oil Creek, Pennsylvania, in 1860. From this center prospectors spread out in all directions, making valuable discoveries, until now petroleum production and refining rank among the leading industries of the country, the supply coming from many states.

Natural gas was discovered and first employed for economic purposes at Fredonia, New York, in 1821. In 1841 it was used in the Great Kanawha Valley as a fuel in salt furnaces, but its first extensive use began in 1872 at Fairview, Pennsylvania. It was used in 1885 for iron smelting at Etna Borough near Pittsburg, and in 1886 was piped nineteen miles from Murraysville to Pittsburg. Now natural gas is piped long distances to cities, being used as a fuel in many industries, as well as for domestic heating and lighting.

The following tables give the production of oil and gas from 1904 to 1908 inclusive. The production of oil since 1880 is shown dia-

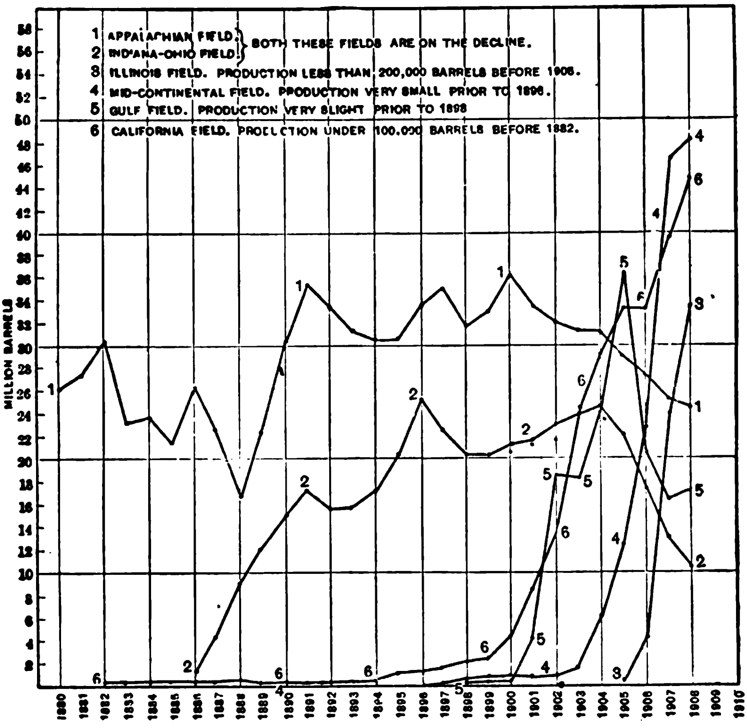

Fig. 41. — Production of oil fields.

gramatically in Fig. 41. Where the production has fallen below 200,000 barrels no attempt has been made to show it. This affects only the Gulf and Mid-Continental fields.

Quantity and Value of Petroleum Produced in United States, 1904–1908

	1904		1905		1906	
	Quantity bbl.	Value	Quantity bbl.	Value	Quantity bbl.	Value
Pennsylvania	11,125,762	$18,222,242	10,437,195	$14,653,278	10,256,893	$16,596,943
Ohio	18,876,631	23,730,515	16,346,660	17,054,877	14,787,763	16,997,000
West Virginia	12,644,685	20,583,781	11,578,110	16,132,631	10,120,935	16,170,293
California	29,649,434	8,265,434	33,427,473	8,201,846	33,098,598	9,553,430
Kentucky and Tennessee	998,284	984,938	1,217,337	943,211	1,213,548	1,031,629
Colorado	501,763	578,035	376,238	337,606	327,582	262,675
Illinois	—	—	181,084	116,561	4,397,050	3,274,818
Indiana	11,339,124	12,235,674	10,964,247	9,404,909	7,673,477	6,770,066
Kansas	4,250,779	5,447,622	12,013,495	6,546,398	21,718,648	9,615,198
Oklahoma	1,366,748					
Texas	22,411,413	8,156,220	28,136,189	7,552,262	12,567,897	6,565,578
Wyoming	11,542	80,794	8,454	51,545	7,000	49,000
Louisiana	2,958,958	1,073,594	8,910,416	1,601,325	9,077,528	3,557,838
New York	1,113,264	1,811,837	1,117,582	1,557,630	1,243,517	1,995,377
United States	117,080,960	101,175,455	134,717,580	84,157,399	126,493,936	92,444,735

QUANTITY AND VALUE OF PETROLEUM PRODUCED IN UNITED STATES, 1904–1908 — *Continued*

	1907		1908	
	QUANTITY bbl.	VALUE	QUANTITY bbl.	VALUE
Pennsylvania . . .	9,999,306	$17,579,706	9,424,325	$16,881,194
Ohio	12,207,448	14,769,888	10,858,797	14,178,502
West Virginia . . .	9,095,296	15,852,428	9,523,176	16,911,865
California	39,748,375	14,699,956	44,854,737	23,433,502
Kentucky and Tennessee	820,844	862,396	727,767	706,811
Colorado	331,851	272,813	379,653	346,403
Illinois	24,281,973	16,432,947	33,685,106	22,648,881
Indiana	5,128,037	4,536,930	3,283,629	3,203,883
Kansas	45,933,649	18,478,658	1,801,781	746,695
Oklahoma			45,798,765	17,694,843
Texas	12,322,696	10,401,863	11,206,464	6,700,708
Wyoming	9,339	21,883[1]	17,775	27,920[1]
Louisiana	5,000,221	4,063,033	6,835,130	4,131,173
New York	1,212,300	2,127,748	1,160,128	2,071,533
United States . . .	166,095,335	120,106,749	179,572,479	129,706,258

PRODUCTION OF PETROLEUM IN THE UNITED STATES, 1904–1908, BY FIELDS, IN BARRELS

	1904	1905	1906	1907	1908
Appalachian . . .	31,408,567	29,366,960	27,741,472	25,342,137	24,945,517
Lima-Indiana . . .	24,689,184	22,294,171	17,554,661	13,121,094	10,032,305
Illinois	——	181,084	4,397,050	24,281,973	33,685,106
Mid-Continent . .	6,186,629	12,535,777	22,838,553	46,846,267	48,323,810
Gulf	24,631,269	36,526,323	20,527,520	16,410,299	17,318,330
California	29,649,434	33,427,473	33,098,598	39,748,375	44,854,737
Other	515,877	385,792	336,082	345,190	412,674
Total	117,080,960	134,717,580	126,493,936	166,095,335	179,572,479

The average price per barrel of petroleum naturally varies somewhat from year to year. In 1885 it was 87⅞ ¢; in 1890 86¾ ¢; in 1900, $1.194; in 1903, 94¼ ¢; in 1906, .731 ¢; and in 1908, 722 ¢.

The total number of barrels of petroleum produced in the United States from 1859 to the end of 1908 was 1,986,180,942, with a value of $1,784,583,943, while the total value of natural gas produced in the United States from 1882 to the end of 1908 was $581,479,911.

The world's production of petroleum from 1904 to 1908 was as follows: —

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[1] Includes Utah.

WORLD'S PRODUCTION OF CRUDE PETROLEUM, 1904–1908, BY COUNTRIES

(Barrels of 42 gallons)

COUNTRY	1904	1905	1906	1907	1908		PERCENTAGE OF TOTAL PRODUCTION
					Barrels	Metric tons	
United States	117,080,960	134,717,580	126,493,936	166,095,335	179,572,479	23,942,997	63.09
Russia	78,536,655	54,960,270	58,897,311	61,850,734	62,186,447	8,291,526	21.85
Sumatra, Java, and Borneo	7,682,014	8,586,804	8,662,572	8,377,099	8,752,822	1,143,243	3.08
Galicia	5,947,383	5,765,317	5,467,967	8,455,841	12,612,295	1,754,022	4.43
Roumania	3,599,026	4,420,987	6,378,184	8,118,207	8,252,157	1,147,727	2.90
India	3,385,468	4,137,098	4,015,803	4,344,162	5,047,038	672,938	1.77
Japan	1,418,767	1,341,157	1,710,768	2,010,639	2,070,929	276,124	.73
Mexico	——	——	——	1,000,000	3,481,410	464,188	1.22
Canada	552,575	634,095	569,753	788,872	527,987	70,400	.19
Germany	637,431	560,963	578,610	756,631	1,009,278	141,900	.35
Peru	345,834	447,880	534,929	741,226	1,011,180	134,824	.36
Italy	25,476	44,027	53,577	59,875	[1] 60,000	8,344	.03
Other	[1] 40,000	[1] 30,000	[1] 30,000	[1] 30,000	[1] 30,000	4,000	
	219,251,589	215,646,178	213,393,410	262,628,621	284,614,022	38,052,233	100.00

APPROXIMATE VALUE OF NATURAL GAS PRODUCED IN THE UNITED STATES, 1904–1908

STATE	1904	1905	1906	1907	1908
Pennsylvania	$18,139,914	$19,197,336	$18,558,245	$18,844,156	$19,104,944
New York	522,575	623,251	672,795	766,157	959,280
Ohio	5,315,564	5,721,462	7,145,809	8,718,562	8,244,835
West Virginia	8,114,249	10,075,804	13,735,343	16,670,962	14,837,130
Illinois	4,745	7,223	87,211	143,577	446,077
Indiana	4,342,409	3,094,134	1,750,715	1,572,605	1,312,507
Kansas	1,517,643	2,261,836	4,010,986	6,198,583	7,691,587
Missouri	6,285	7,390	7,210	17,010	22,592
California	114,195	133,696	134,560	168,397	307,652
Alabama	14,082	14,409	150,695	178,276	236,837
Texas					
Louisiana	——	1,500			
Kentucky	322,104	237,290	287,501	380,176	424,271
Tennessee	300	300	300	300	350
Arkansas and Wyoming	6,515	21,135	34,500	126,582	164,930
Colorado	14,300	20,752	22,800		
South Dakota	12,215	15,200	15,400	19,500	24,400
Oklahoma	49,665	130,137	259,862	417,221	860,159
North Dakota and Oregon	——	——	——	335	2,823[2]
Total	$38,496,760	$41,562,855	$46,873,932	$54,222,399	$54,640,374

EXPORTS OF MINERAL OILS

KIND	1905	1906	1907	1908
Crude	$6,085,592	$7,731,226	$6,333,715	$6,519,849
Naphtha	2,214,609	2,488,401	3,676,206	4,542,551
Illuminating	54,900,649	54,858,312	59,635,208	75,988,256
Lubricating and Paraffin	14,312,383	18,689,622	19,210,353	18,971,436
Residuum	2,127,696	1,971,305	2,527,582	2,793,363
Total	$79,640,929	$85,738,866	$91,383,064	$108,815,455

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[1] Estimated.

[2] Includes Iowa.

IMPORTS OF NATURAL GAS

1904	$34,828	1907	$32,107
1905	49,237	1908	22,003
1906	36,906		

Production of Asphalt and Bituminous Rock. — The production of these two substances by kinds and by states as well as the imports and exports are given below.

PRODUCTION OF ASPHALT, 1904 TO 1908, BY VARIETIES, IN SHORT TONS

VARIETY	1904		1905		1906	
	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE
Bituminous rock	48,439	$142,960	45,302	$136,972	24,085	$70,686
Refined bitumen	1,200	10,800	2,200	22,000	2,543	24,158
Gum	6.637	141,446	3,036	41,438	24,178	341,106
Maltha	3,363	36,320	3,139	34,292	9,900	86,750
Wurtzilite (elaterite)	550	50,000	500	44,000	12,947	159,960
Gilsonite	2,978	14,175	10,916	47,040		
Grahamite	1,000	25,000	——	——	1,952	16,432
Ozokerite and tabbyite	——	——	5	1,500	——	——
Oil asphalt	44,405	459,135	50,169	430,911	62,454	591,248
Total	108,572	$879,836	115,267	$758,153	138,059	$1,290,340

VARIETY	1907		1908	
	QUANTITY	VALUE	QUANTITY	VALUE
Bituminous rock	45,526	$129,040	37,371	$146,821
Refined bitumen	1,744	16,568	4,536	48,780
Gum	5,195	78,400	7,000	88,000
Maltha	13,507	143,758	12,875	162,000
Wurtzilite (elaterite)	422	35,327	450	36,000
Gilsonite	20,285	531,965	18,533	61,824[1]
Grahamite	966	7,743	2,286	20,340
Ozokerite and tabbyite	12	2,148	50	2,500
Oil asphalt	136,204	1,881,540	102,281	1,322,616
Total	223,861	$2,826,489	185,382	$1,888,881

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[1] The curiously large decrease in value as given, does not, it is claimed, represent a decrease in value per ton, but instead indicates a change in conditions of transportation to trunk lines of railroads from the mines.

PRODUCTION OF ASPHALT IN 1908, BY VARIETIES AND BY STATES, IN SHORT TONS

VARIETY	CALIFORNIA		UTAH		OKLAHOMA	
	Quantity	Value	Quantity	Value	Quantity	Value
Bituminous rock	27,118	$91,998	——	——	——	——
Mastic	3,250	36,563	——	——	——	——
Refined bitumen	7,000	88,000	——	——	——	——
Maltha	12,759	158,520	——	——	116	$3,480
Uintaite (gilsonite)	——	——	18,533	$61,824	——	——
Wurtzilite (elaterite) and tabbyite	——	——	500	38,500	——	——
Grahamite	——	——	——	——	2,286	20,340
Oil asphalt	85,114	972,176	——	——	——	——
	135,241	$1,347,257	19,033	$100,324	2,402	$23,820

VARIETY	KENTUCKY		TEXAS	
	Quantity	Value	Quantity	Value
Bituminous rock	10,253	$54,823	——	——
Mastic	1,286	12,217	——	——
Oil asphalt	——	——	17,167	$350,440
	11,539	$67,040	17,167	$350,440

Since deposits of the purer type, such as lake asphalt, are very scarce in the United States, the supply for domestic consumption is obtained from foreign countries. The imports for the last five years are given below: —

ASPHALT IMPORTED FOR CONSUMPTION INTO THE UNITED STATES, 1904–1908, IN SHORT TONS

YEAR	CRUDE		DRIED OR ADVANCED		BITUMINOUS LIMESTONE		TOTAL	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1904	117,184	$490,809	16,766	$100,081	6,496	$20,236	140,446	$116,126
1905	85,014	381,474	9,688	78,639	5,895	19,183	100,597	479,296
1906	100,818	355,493	14,178	114,076	5,086	15,110	120,082	484,679
1907	142,494	502,811	13,535	127,024	4,925	15,629	160,954	648,564 [1]
1908	137,808	532,297	7,642	67,364	6,224	20,758	151,674	624,979 [1]

[1] Imports for 1907 include $3,100 of manufactures; 1908, $4,560.

Most of the asphalt imported from foreign countries comes from the island of Trinidad, but other important sources are Venezuela

(Bermudez), Cuba, Germany, Italy, and Mexico. Small amounts are also brought from Switzerland, France, the United Kingdom, Turkey in Asia, Colombia, and Netherlands.

The ozokerite imported for consumption in 1907 amounted to 1,451,231 pounds, valued at $149,507; in 1908 it amounted to 3,595,393 pounds, valued at $374,953.

During the fiscal year ending June 30, 1908, domestic asphalt and manufactured asphaltic material to the value of $451,968 were exported from the United States to other countries, as against similar exports valued at $374,476 during the fiscal year ending June 30, 1907.

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CHAPTER III

BUILDING STONES

UNDER this term are included all stones for ordinary masonry construction, as well as for ornamentation, roofing, and flagging. The number of different kinds used is very great, and includes practically all varieties of igneous, sedimentary, and metamorphic rocks, but a few stand out prominently on account of their widespread occurrence and durability.

The cost of a building stone naturally exerts decided influence on its use. Since the ease of splitting and dressing a stone influences its cost, the texture is also of importance. Color is another factor in determining the value of a building stone, and this, together with other considerations, sometimes gets a fashion leading to the widespread use of certain stones. This has been well illustrated in the eastern cities of the United States, where, for many years, Connecticut brownstone was in such great demand for use in building private dwellings that much inferior stone was put on the market. More recently Indiana limestone and Ohio sandstone have met the popular fancy, and these two are now used in vast quantities.

Properties of Building Stones[1] (1-6). — The following properties have an important bearing on the value of a building stone: —

Color. — The color of rocks varies greatly, and those shown by common building stones include white, black, brown, red, yellow, and buff, while some are green, blue, or mottled. The color may vary in the same quarry.

In igneous rocks the color may be that of the prevailing mineral, as in pink granite, where there is an excess of pink feldspar; or it may be a composite due to the blending of the colors of several minerals, as in the case of ordinary gray granite, where the color results from the mixture of black mica and whitish quartz and feldspar. Sedimentary rocks commonly owe their color to ferruginous cements, or to carbonaceous matter. The former give brown, yellow, red, or green colors depending on the condition of oxidation and form of combination of the iron, while the latter produces gray, black, and bluish tints depending on the amount present. Sandstone and limestone free from either of these coloring agents are nearly if not quite white.

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[1] Only the more important ones are here considered. Excellent detailed discussions will be found in Refs. 3, 30, 41, 43 *a*, 51.

Some stones change color on exposure to the air. For example, limestones or sandstones containing carbonaceous matter may bleach; some black marbles fade to a white or gray; and some red and green roofing slates, as well as a few red granites, change color. Oxidation of evenly distributed pyrite may change gray or bluish-gray sandstones to buff color. If the minerals responsible for such change in color are not uniformly distributed, the stone assumes a blotchy appearance, but such changes are not necessarily an indication of deterioration.

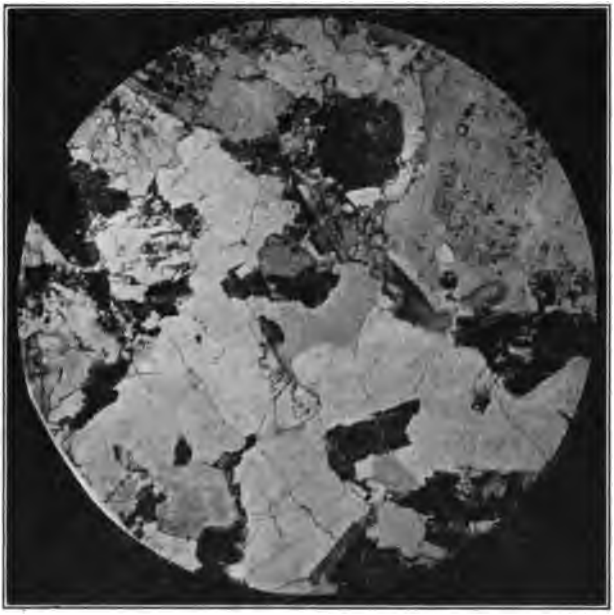

FIG. 42. — Photomicrograph of a section of Granite. (Photo loaned by A. B. Cushman.)

Texture. — Building stones vary in their texture from coarse-grained granites and conglomerates to fine-grained sandstones, limestones, and porphyries.

Texture is an important property, for it influences both the durability and the cost of stone. Other things being equal, a fine-grained rock is not only more durable, but splits better and dresses more evenly, than a coarse-grained rock. Uneven texture, whether due to mineral grains or cement, is undesirable, since it often causes uneven weathering.

Density. — On the whole, dense stones resist weather better than porous ones, but there is great difference in the density of building stones.

In general, though with some exceptions, igneous and metamorphic rocks have high density because of the close interlocking of the crystalline grains. Sedimentary rocks of clastic origin, on the other hand, have less closely fitting grains, and unless the latter are very small, or the pores well filled with cement, they are apt to be porous.

The specific gravity of a stone indicates its density; and from the specific gravity the weight per cubic foot may often be approximately estimated by multiplying it by 62.5, the weight of an equal volume of water. While sufficiently accurate for very dense stones, this method is liable to lead to incorrect results when applied to very porous rocks. Following are some average specific gravities of common building stones, as given by Hermann (1): granite, 2.65; syenite, 2.80; diabase, 2.80; gabbro, 2.95; serpentine, 2.60; gneiss, 2.65; limestone, 2.60; dolomite, 2.80; sandstone, 2.10; slate, 2.70.

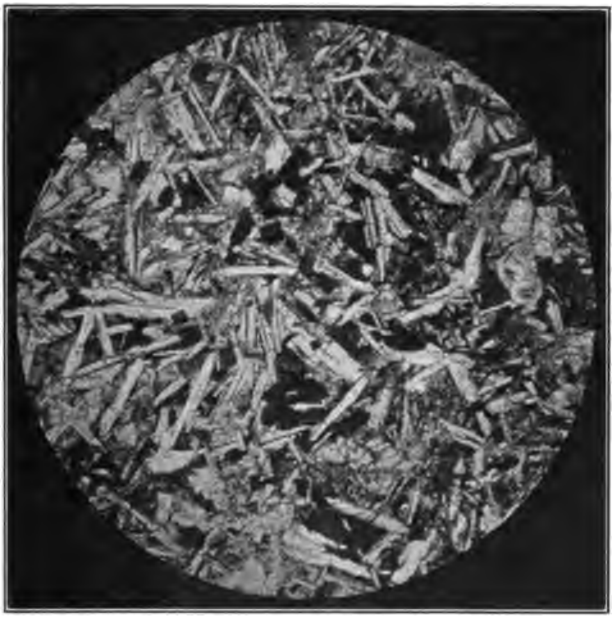

Fig. 43. — Photomicrograph of a section of Diabase. (Photo loaned by A. B. Cushman.)

Hardness. — The hardness of a building stone is not necessarily dependent on the hardness of its component minerals, but is largely influenced by their state of aggregation, and to some extent their hardness.

For example, a sandstone composed of quartz grains, but with little cementing material, may be so soft as to crumble easily in the fingers; while a limestone, whose grains of soft carbonate of lime fit closely and are firmly cemented, may be difficult to break with a hammer. The nature of the cement in sedimentary rocks, that is, whether it is lime, silica, or iron, will also affect the hardness of the stone. Crystalline rocks owe their great hardness to the firm interlocking of the mineral grains. The abrasive resistance (10) of a stone will depend in part on the state of aggregation of the mineral particles, and in part on the hardness of the grains themselves. Some stones wear very unevenly because of their irregularity of hardness, and such may be less desirable than one which is uniformly soft.

No standard form of abrasion test exists, and yet one should be applied to those stones which are used for paving, steps, or flooring, as well as to those placed in situations where they may be subjected to the attacks of wind-blown sand, or the rubbing action of running water.

Strength. — Two kinds of strength, compressive and transverse, are to be considered in building stones.

The compressive or crushing strength, which is expressed in pounds per square inch, is the resistance which the rock offers to a crushing force, and is dependent chiefly on the size of the grains, state of aggregation, and mineral composition. Because of the close interlocking of the grains of igneous rocks they are stronger than those of sedimentary origin, in which the strength is due chiefly to the cement which binds the grains together. Sedimentary rocks show greatest strength when dry, or when pressure is applied at right angles to the bedding.

Few building stones when in use are subjected to pressures even approximately equal to their crushing strength. No domestic building stone at present used in the eastern market has a crushing strength of less than 6000 pounds, yet the pressure even in the tallest buildings does not require a stone with a crushing strength exceeding 314.6 pounds, and this includes the factor of safety of twenty usually allowed by architects. Computations show that a stone at the base of the Washington monument sustains a maximum pressure of 6292 pounds per square inch, which includes the usual factor of safety of twenty; the crushing strength of the stone used in the base of the monument is however not less than 10,000 to 12,000 pounds per square inch.

The crushing strength of some soft limestones or sandstones may be but little above 3000 pounds per square inch, while that of diabase often exceeds 30,000 pounds per square inch. The accompanying table gives the crushing strength of a number of stones. (Many others are given in the state reports.)

CRUSHING STRENGTH OF BUILDING STONES

Granite, Vinal Haven, Me.	13,381
Granite, East Saint Cloud, Minn.	28,000
Granite, Port Deposit, Md.	19,750
Dolomite marble, Tuckahoe, N.Y.	13,076
Limestone, Caen, France	3,550
Sandstone, Portland, Conn.	13,310
Sandstone, E. Long Meadow, Mass.	8,812

Wide variations sometimes exist in stones from different parts of the same quarry, or in stones from the same locality tested at different times. The published crushing tests of different stones cannot really be fairly compared because all have not been tested under exactly the same conditions.

Transverse Strength. — The transverse strength is the load which a bar of stone, supported at both ends, is able to withstand without breaking. It is measured in terms of the *modulus of rupture,* which represents the force necessary to break a bar of one square inch cross section, resting on supports one inch apart, the load being applied in the middle. Although stones in buildings are rarely, if ever, crushed, they are frequently broken transversely, and therefore a knowledge of the transverse strength is of more importance than the crushing strength. A high crushing strength does not necessarily mean a high transverse strength. Unfortunately few stones have been tested in this manner.

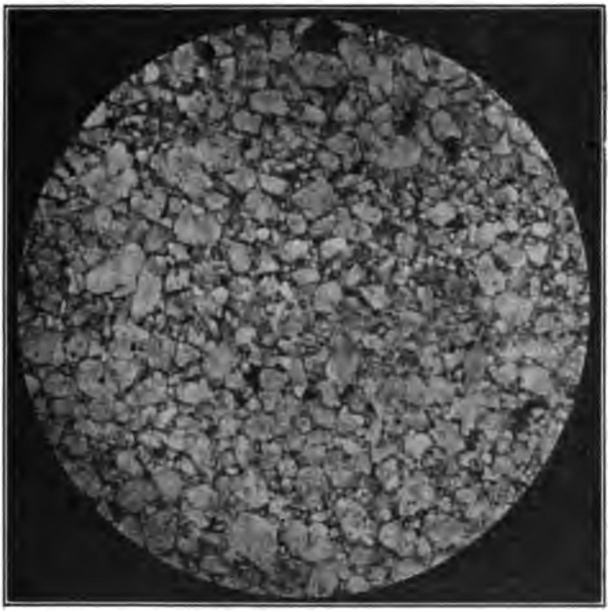

FIG. 44. — Photomicrograph of a section of quartzitic sandstone. (Photo loaned by A. B. Cushman.)

Porosity and Ratio of Absorption. — The porosity of building stones varies widely. Most igneous rocks have little pore space and hence absorb little water; but sedimentary rocks, especially sandstones, are often very porous.

Many rocks, especially those of the sedimentary class, contain water in their pores when first quarried. This is known to quarrymen as *quarry* *water*, and it is present in some porous sandstones in sufficient quantities to interfere with quarrying during freezing weather. Mineral matter in solution in the quarry water is deposited between the grains when the water evaporates, often in sufficient quantities to perceptibly harden the stone.

Water is also present in the joint planes, and by its passage along these planes causes oxidation and rusting of the iron of the rock-forming minerals. This discolors the stone along and on either side of the joint planes, giving rise to a yellow color known as *sap*.

Resistance to Frost. — Building stones show a varying degree of resistance to frost.

Dense rocks, like granites, quartzites, and many limestones, and even some very porous rocks, are little affected; but many porous and laminated rocks, like open sandstones and schists, disintegrate under frost action. This is due to the fact that moisture absorbed in the warmer weather, on freezing in the pores, expands, and either forces off small pieces or disrupts the stones. Since clay readily absorbs water, clayey rocks are sometimes similarly affected.

Resistance to Heat. — All rocks expand when heated, and contract when cooled, but do not shrink down to their original dimensions. This permanent increase in size is termed *permanent swelling*, and though small when figured for one linear foot, is appreciable in long pieces.

The following figures give the average of a number of tests of permanent swelling in stone bars 20 inches long, heated from 32° F. to 212° F., and then cooled to the original temperature: granite, .009 inch; marble, .009 inch; limestone and dolomites, .007 inch; sandstone, .0047.

The most severe test of a stone's resistance to rapid changes of temperature is to heat it to about 800° C. and then immerse it in cold water. Quartzites and hard sandstones withstand such treatment best; some granites crack and crumble, and the carbonate rocks change to lime.

Chemical Composition. — Many chemical analyses of building stones have been made, but most of them are of little value, largely because they tell us nothing regarding the physical properties of the stone. They are perhaps of most value in the case of sedimentary rocks. The chemical analysis of a limestone will indicate whether it is dolomitic or not, also whether it is clayey in its character. So too the analysis of a sandstone will indicate whether it is siliceous or clayey.

Life of a Building Stone. — This may be considered as the period of time a stone will stand exposure to the weather without showing signs of decay. Even for the same stone, it may vary with location and climate. Julien makes the following deductions from observations made on stones in use: —

Coarse brownstone	5–15 years
Fine-laminated brownstone	20–50 years
Coarse fossiliferous limestone	20–40 years
Coarse dolomitic marble	40 years
Fine-grained marble	50–100 years
Granite	75–200 years
Quartzite	75–200 years

Structural Features affecting Quarrying. — All rocks are traversed by planes of separation of one sort or another. In sedimentary rocks these consist of bedding and joint planes; in igneous rocks, the latter alone are present; and in metamorphic rocks, joint planes, a banding of minerals and, very often, cleavage planes.

Bedding planes. — (Pl. XIII, and Pl. XVIII, Fig. 1.) These may be either an advantage or a disadvantage to the quarryman. They are desirable because they facilitate the extraction of the stone; but if numerous and closely spaced, the layers may be too thin for any purpose except flagging. They often serve as a means of entrance for the agents of weathering, and the stone may be disintegrated along the bedding planes while elsewhere fresh.

Incipient planes of weakness, due either to the arrangement of minerals or to microscopic fractures in them, often give rise to planes of easy splitting which are of great value in quarrying, notably of granite. The most prominent plane is called *rift;* and a less prominent vertical plane, approximately at right angles to the rift, is called the *grain.* Granites often show a sheeted (Pl. XII, Fig. 1) structure, due to the presence of horizontal joints. These are slightly curved, and hence tend to separate the granite mass into a series of lenses.

The position of the beds exerts an important influence on the cost of quarrying. When horizontal and of different quality, it may often be necessary to strip off worthless rock in order to reach the beds of good quality. In such cases, there is often less stripping to do in quarries opened on gently sloping ground. In regions of steep dip, it is sometimes possible to work the quarry as a cut, extracting the desired beds and leaving useless ones standing.

GRANITES

Characteristics of Granites (3, 43*a*). — As commonly used by quarrymen, the term *granite* includes all igneous rocks and gneiss; but in this book it is used in the geological sense, which is more restricted. From the geological standpoint a granite is a holocrystalline, plutonic igneous rock consisting of quartz, orthoclase feldspar, and either mica or hornblende, or both. There are also varying but usually small quantities of other feldspars, and there may be subordinate accessory minerals, such as pyrite, garnet, tourmaline, and epidote.

Granites vary in texture from fine to coarse grained, and in some cases are porphyritic. They pass into gneisses by such insensible gradations that no sharp line can be drawn between the two. In color they vary, being, most commonly, gray, mottled gray, red, pink, white, or green, according to the color or abundance of the component minerals. Most granites are permanent in their color, but some of bright red color bleach on continuous exposure to sunlight.

The average specific gravity of granites is 2.65, which corresponds to a weight of 165.6 pounds per cubic foot. They commonly contain less than 1 per cent of water, and often absorb two or three tenths more. Their crushing strength varies, but is apt to lie between 15,000 and 30,000 pounds per square inch.

Granites are among the most durable of building stones, but there is some variation in the durability of the different kinds. Other things being equal, fine-grained granites are more durable than coarse-grained, being less easily affected by changes of temperature. One of the most beautiful granites known, the Rapikivi granite of Finland, lacks in durability on this account. Pyrite and marcasite are injurious minerals, since they rust rapidly and may discolor the stone in an unsightly manner. Very few granites now in use show signs of decay; but in those that do, the darker silicates are rusted, the luster of the feldspar is dulled, and, in some cases, the stone has begun to disintegrate.

Distribution of Granites in the United States (3). — Granite usually occurs in batholytic masses sometimes forming the cores of mountain chains. Removal of the overlying strata by denudation has revealed the granite, which, owing to its greater durability, is often left standing as peaks or domes by the farther removal of the surrounding, weaker strata. Granites show a wide geologic range, but most known occurrences are associated with the older formations.

Granite forms an important source of durable building stone widely distributed in the United States (Fig. 45); but nearly 70 per cent of that quarried comes from the Atlantic states. There are several areas which will be briefly considered.

Eastern Crystalline Belt (3, 11, 19, 26, 31, 44, 45). — From northeastern Maine southwestward to eastern Alabama there is an important belt of granites and gneisses, mostly of pre-Cambrian age. Those at the northeastern end of the belt, as far south as New York, are most extensively quarried, largely because of their pecul-

PLATE XII

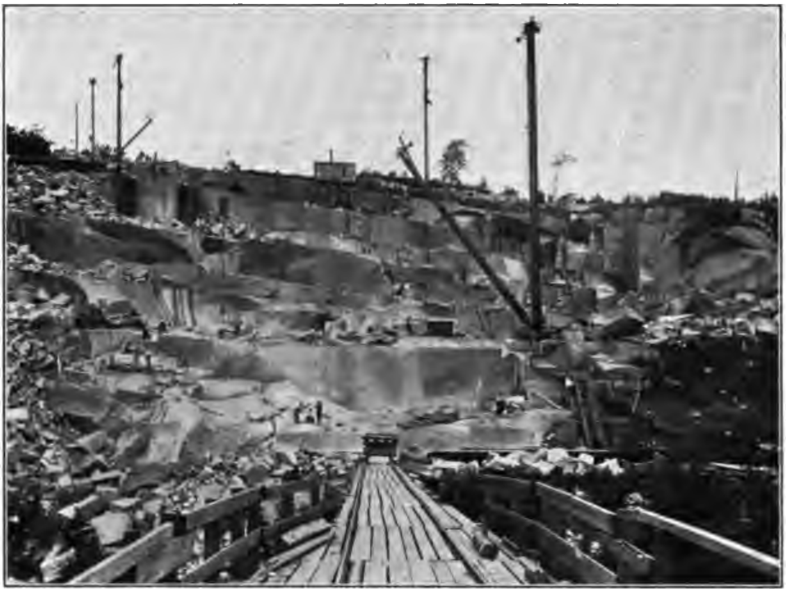

FIG. 1. — Granite quarry, Hardwick, Vt. (*Photo. by G. H. Perkins.*)

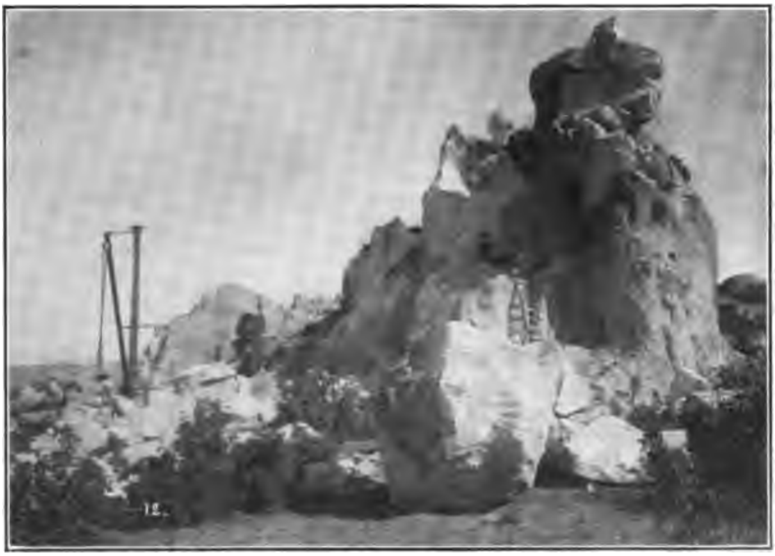

FIG. 2. — Quarry in volcanic tuff, north of Phœnix, Ariz.

iarly favorable location. In this belt those of Quincy, Massachusetts (28), Barre, Vermont (44), and Westerly, Rhode Island (41), are of value for monumental work. Many large quarries have also been opened up in Maine (25), but their output is employed mainly for structural work. A gneissic granite quarried at Port Deposit, Maryland (26), a white granite from Mt. Airy, North Carolina (36), as well as a pinkish granite worked at Stone Mountain, Georgia (20), are also of some importance. Another important granite area is located near Richmond, Virginia. (46).

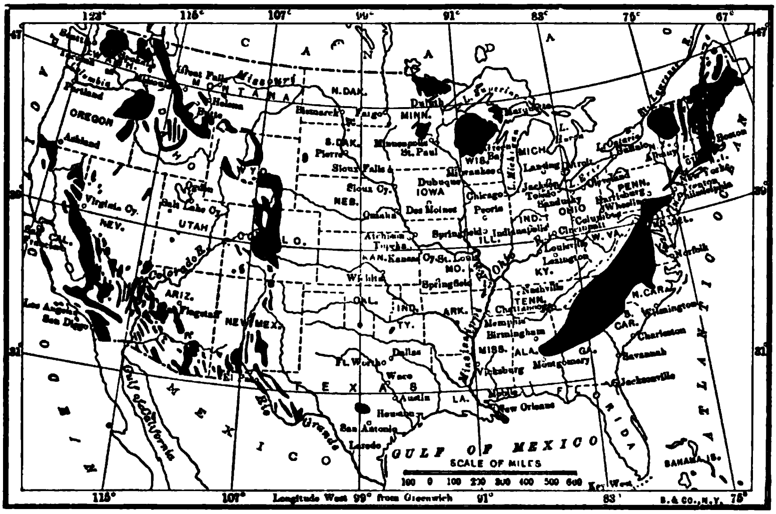

FIG. 45. — Map showing distribution of crystalline rocks (mainly granites) in United States. (*After Merrill, Stones for Building and Decoration.*)

Minnesota-Wisconsin Area (51). — There are several detached areas in these two states, some of which supply granites of value for ornamental work. That from Montello, Wisconsin, bears a high reputation, and those from Wausau, Wisconsin, and Ortonville, Minnesota, are favorably known.

Southwestern Area. — This includes portions of Missouri, Arkansas, Oklahoma, and Texas.

These four states contain small areas, worked mainly to supply a local demand. Those of southeastern Missouri vary from light gray to red in color and fine grained to porphyritic in texture. Some of the rock is rhyolite. The region around Fredericktown is important (30). Important granite deposits are known in the Arbuckle and Wichita Mountains of Oklahoma (38), but their development thus far has been slight. Arkansas contains quarries of syenite west of Little Rock (3), and for purposes of convenience it is mentioned under granite. In Texas quarries have been opened in Llano County, and yield both pink and gray granite (3).

Western States. — There are many areas of true granite, and closely allied rocks such as grano-diorite and rhyolite in the western states. The central portion of the Black Hills of South Dakota is a great granite mass, but little of it is quarried. Granites are known in Colorado (17), and quarried to some extent, and the rhyolites of Castle Rock are of considerable importance. In California the grano-diorite mass forming the central portion of the Sierra Nevada Mountains yields an inexhaustible supply, which is quarried at several points. Montana, Washington (47), and Oregon also contain granites which are quarried for local use. On the whole, however, the Cordilleran granite industry is somewhat restricted because of lack of demand.

Uses of Granite. — On account of its massive character and durability, granite is much employed for massive masonry construction, while some of the granites that take and preserve a high polish, and are susceptible of being carved, are in great demand for ornamental and monumental work. Because of its greater durability, granite has in recent years largely replaced marble for monumental purposes.

The refuse of the quarries is often dressed for paving blocks or crushed for roads and railroad ballast. The size of the blocks which can be extracted from a granite quarry depends in part on the spacing of the joint planes, in part on the perfection of development of the rift, some of the monoliths that have been quarried being of immense size: for example, one from Stony Creek, Connecticut, measured 41 ft. × 6 ft. × 6 ft.; one from Vinal Haven, Maine, 60 ft. × 5½ ft.; one from Barre, Vermont, 60 ft. × 7 ft. × 6 ft.

Miscellaneous Igneous Rocks (3). — But little space need be given to these, for they are of minor importance as compared with the granites. In the eastern states the diabase or trap rock is quarried at several points in Connecticut, New York, New Jersey, and Pennsylvania. Owing to its great hardness it is only occasionally used for dimension blocks, its chief value being for paving blocks and road metal. The basaltic rocks of the western states, especially those of Washington and California, are often employed for similar purposes. Anorthosites and gabbros, some of the former being of highly ornamental character when polished, occur in the

Adirondack Mountains, New York; they are, however, but little utilized. Gabbros have been quarried for local use in Maryland and Minnesota, and diorites have been quarried to a small extent at scattered localities. Some of the porphyries and rhyolites of the Atlantic states possess considerable beauty when polished. A handsome porphyry is quarried in Wisconsin (51), and in the Cordilleran region both rhyolite and porphyry occur in numerous localities. Andesite tuffs are quarried in Colorado, and consolidated volcanic tuffs have also been used to some extent for building in Arizona.

LIMESTONES AND MARBLES

General Characteristics (1, 3). — A great series of sedimentary and metamorphic rocks, composed chiefly of carbonate of lime, or, in the case of dolomite, of carbonate of lime and magnesia, is included under the term *limestone and marble.* These rocks also contain varying, but usually small, amounts of iron oxide, iron carbonate, silica, clay, and carbonaceous matter. When of metamorphic character various silicates, such as mica, hornblende, and pyroxene, etc., may be present.

These calcareous rocks vary in texture from fine-grained, earthy, to coarse-textured, fossiliferous rocks, and from finely crystalline to coarsely crystalline varieties. There is, also, great range in color, the most common being blue, gray, white, and black, but beautiful shades of yellow, red, pink, and green, usually due to iron oxides, are also found. Their crushing strength commonly ranges from 10,000 to 15,000 pounds per square inch, while their absorption is generally low.

The mineral composition of limestone exerts a strong influence on its durability. Those limestones which are composed chiefly or wholly of carbonate of lime are liable to solution in waters containing carbon dioxide; but dolomite limestones, especially coarse-grained ones, disintegrate rather than decompose. Streaks of mineral impurities cause the stone to weather unevenly. Pyrite is an especially injurious constituent, not only on account of its rusting, but also because the sulphuric acid set free by its decomposition attacks the stone. Tremolite, which is found in some dolomitic marbles, is also liable to cause trouble by its decay. Black or gray limestones will sometimes bleach on exposure.

Varieties of Limestones. — In the geological sense limestones are of sedimentary origin, while marbles are of metamorphic character, but in the trade the term *marble* is applied to any calcareous rock capable of taking a polish. In addition to the different varieties of marble and the ordinary limestones, there are certain kinds of calcareous rock to which special names are given, as follows: —

Chalk is a fine, white, earthy limestone, composed chiefly of foraminiferal remains.

Coquina is a loosely cemented shell aggregate, like that found near St. Augustine, Florida.

Dolomite, or *dolomitic limestone*, composed of carbonate of lime and magnesia, and to the eye alone often is indistinguishable from limestone.

Fossiliferous limestones is a general term applied to those limestones which contain many fossil remains. Under this heading are included crinoidal limestone and coral-shell marble.

Hydraulic limestone, an argillaceous limestone containing over 10 per cent of clayey impurities. Used mainly for cement manufacture (p. 139).

Lithographic limestone is an exceedingly fine grained, crystalline limestone, of gray or yellowish hue. It is used for lithographic and not structural work.

Oölitic limestone, composed of small, rounded grains of concretionary character.

Stalactitic and *stalagmitic deposits*, formed on the roofs and floors of caves, respectively, are often of crystalline texture and beautifully colored, and, when of sufficient solidity, are known as onyx marble.

Travertine, or *calcareous tufa*, a limestone deposited from springs. It is often sufficiently hard and durable for building, in mild climate, but rarely occurs in deposits of large size.

Distribution of Limestones in the United States. — Limestones are found in many states, and in all geological formations from Cambrian to Tertiary, but those of the Paleozoic, which are much used in the eastern and central states, are more extensive and more massive than those of later formations. Although many large quarries have been opened to supply a local demand, the product is shipped to a distance from only a few localities. At present the sub-Carboniferous Bedford (22) oölitic limestone of Indiana (Pl. XIII) is, perhaps, the most widely used limestone in the United States. It occurs in massive beds from 20 to 70 feet thick, and is said to underlie an area of more than 70 square miles. Although soft and easily dressed, it has good strength, and has been used in many important cities of the United States. The same rock is quarried at Bowling Green, Ky.

In the eastern and central states the Paleozoic limestones are worked at many points, mainly to supply a local demand (3).

Cretaceous limestones are worked in Kansas, Nebraska, and Iowa, although the most important sources are in the Paleozoic formations.

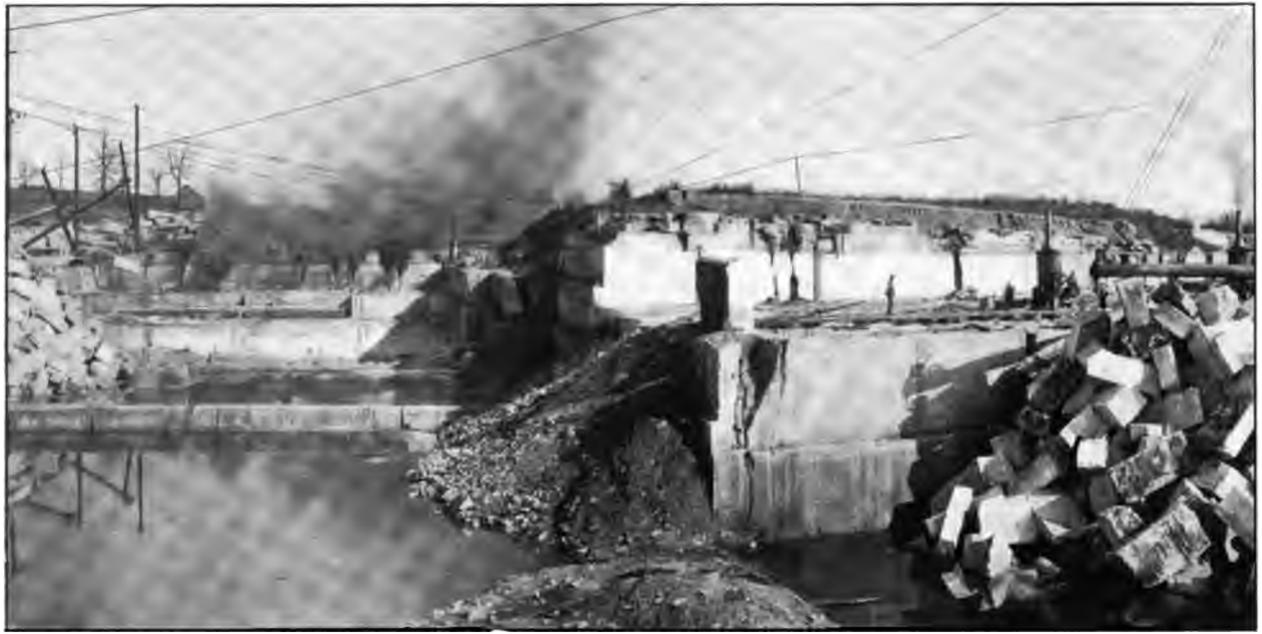

Plate XIII. — Quarry in limestone, Bedford, Ind. (*Photo., Bedford Quarries Co.*) A horizontally bedded limestone, showing some weathering along the vertical joint planes.

Distribution of Marbles in the United States (3). — While some variegated marbles are produced in the United States, still most of those quarried are white, the greater part of the variegated stones being imported. The main supply comes chiefly from regions of metamorphic rock, the eastern crystalline belt being the principal producer (Fig. 46). Vermont (44, 45) leads all other states in marble production, supplying a large per cent of all the marbles

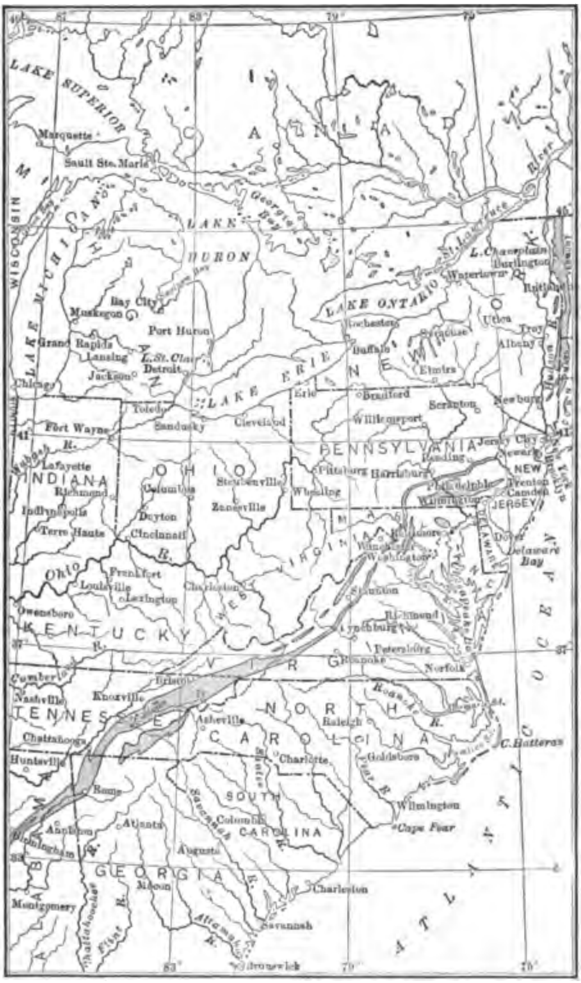

FIG. 46. — Map showing marble areas of eastern United States. (*After Merrill, Stones for Building and Decoration.*)

used for ornamental work in the country. The most important and largest quarries are those at Proctor (Pl. XIV) and West Rutland. At the latter locality the marble bed has a thickness of 150 feet at the top of the quarry, narrowing to 75 feet at the bottom, and is divisible into a series of well-marked layers of varying thickness, quality, and color (45).

The Vermont marbles usually show a bluish-gray or whitish ground, the latter often showing a pinkish or creamy shade, and traversed by veins or markings of a green or brown color.

A beautifully colored series of variegated marbles[1] is quarried at Swanton, Vt. (45), and much used throughout the United States for flooring and wainscoting. Owing to their highly siliceous character they show excellent wearing qualities. White marbles for structural work are quarried at Lee, Massachusetts (3), and at South Dover and Gouverneur, New York (3, 35), but gray ones are also obtained from the last-named locality. In Maryland important quarries have been opened up at Cockeysville (26). Large quantities of white and also gray marble are quarried in Pickens County, Georgia (19) (Pl. XV., Fig. 1).

The Trenton limestone in eastern Tennessee (3) supplies marble of pinkish chocolate color with white variegation; and certain layers are rendered peculiarly beautiful by the replacement of the fossils by calcite. It is used chiefly for interior decoration.

Marble has been reported from various states west of the Mississippi, but as yet little quarrying has been done. A large deposit of white marble is said to occur at Marble, Colorado, and that quarried in Inyo County, California, has attracted considerable attention in recent years (16).

Most of the variegated marble used for interior decoration in this country is obtained from foreign countries, especially France, Belgium, Greece, etc. Many of these imported stones are of rare beauty, but are usually unfitted for exterior use in severe climates, a fact often ignored by architects. Although ornamental stones of this class occur in the United States, up to the present time few attempts have been made to place them on the market. This may be due to the fact that most quarrymen do not care to assume the temporary expense which their introduction might involve.

Onyx Marbles (55–56). — Under this term are included two types of calcareous rock, one a hot-spring deposit, or travertine, formed at the surface, the other a cold-water deposit formed in limestone caves in the same manner as stalagmites and stalactites. Cave onyx is more coarsely crystalline and less translucent than travertine onyx. The beautiful

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[1] These should perhaps be more properly classed as calcareous sandstones.

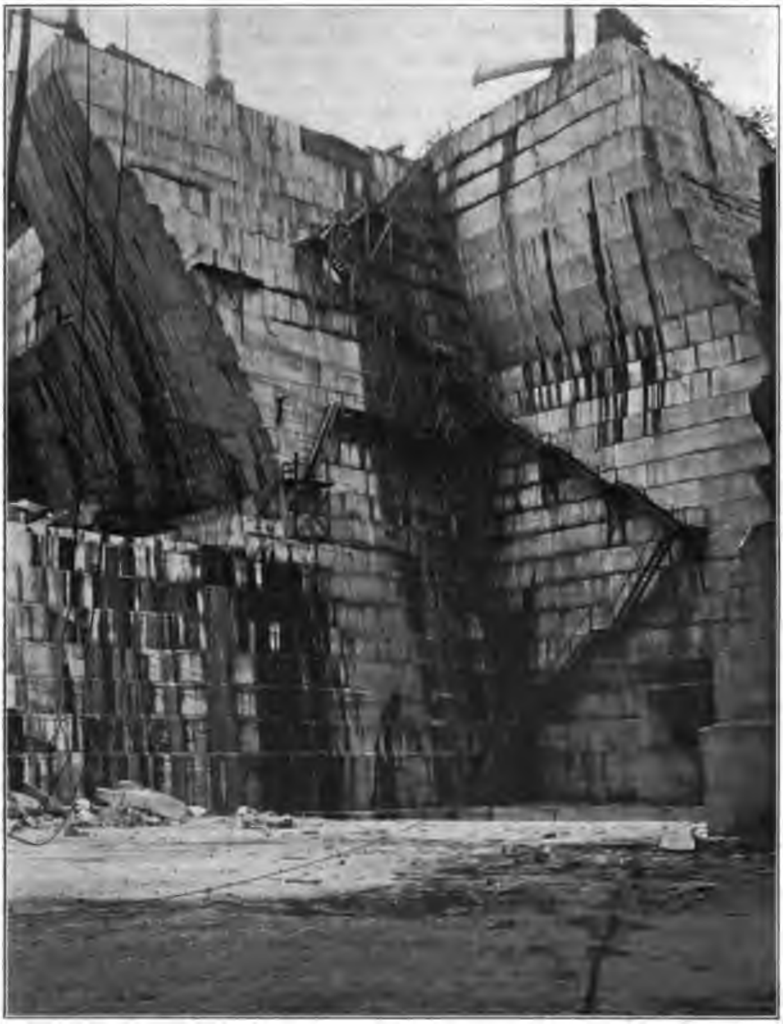

PLATE XIV. — Marble quarry, Proctor, Vt. The banding of the rock is vertical. The horizontal lines are caused by the stone being quarried in benches. (*Photo., Vermont Marble Co.*)

banding of onyx is due to the deposition of successive layers of carbonate of lime, while the colored cloudings and veinings are caused by the presence of metallic oxides, especially iron.

Neither variety of onyx occurs in extensive beds, though both are widely distributed. Onyx is found in Arizona, California, and Colorado, but it has not been developed in any of these states except on a small scale. Most of the onyx used in the United States is obtained from Mexico, though small quantities are obtained from Egypt and north Algeria.

The value of onyx varies considerably, the poorer grades selling for as little as 50 cents per cubic foot, while the higher grades bring $50 or more. The earliest-worked deposits were probably those of Egypt, which were used by the ancients for the manufacture of ornamental articles and religious vessels; and the Romans obtained onyx from the quarries of northern Algeria. Many of the travertine onyx deposits occur in regions of recent volcanic activity, and all of the known occurrences are of recent geological age.

Uses of Limestones and Marbles. — The limestones are used mainly for ordinary dimension blocks, though some, as the Bedford stone, lend themselves well for carved work. The refuse from the quarry may be of value for road material, lime, or Portland cement manufacture. (See reference under Cement.)

Marbles are used in increasing quantities, for ordinary structural work, although many of the lighter-colored ones soon become soiled by dust and smoke. The output of many quarries, especially the Vermont ones, is well adapted to monumental purposes, and these, together with those from Georgia, Tennessee, and California, are much used for wainscoting and paneling. That from Swanton is also well adapted to flooring. Electrical switchboards are now frequently made of marble. The demand for marble tops for tables, washbasins, and similar uses is probably decreasing. The refuse from marble quarries is sometimes utilized for the same purposes as limestone.

SERPENTINE

Pure serpentine is a hydrous silicate of magnesia; but beds of serpentine are rarely pure, usually containing varying quantities of such impurities as iron oxides, pyrite, hornblende, and carbonates of lime and magnesia. The purer varieties are green or greenish yellow, while the impure types are various shades of black, red, or brown. Spotted green and white varieties are called ophiolite or ophicalite.

Serpentine is sometimes found in sufficiently massive form for use in structural or decorative work; but, owing to the frequent and irregular joints found in nearly all serpentine quarries, it is difficult to obtain other than small-sized slabs. Its softness and beautiful color have led to its extensive use for interior decoration; but since it weathers irregularly and loses luster, it is not adapted to exterior work.

Though found in a number of states, most of the numerous attempts to quarry American serpentine have been unsuccessful. Considerable serpentine for ordinary structural work has been quarried in Chester County, Pennsylvania, and a variety known as verdolite has been worked near Easton, Pennsylvania (32). Quarrying operations have also been carried on in the state of Washington (47).

SANDSTONES

General Properties (1, 3). — While most sandstones are composed chiefly of quartz grains, some varieties contain an abundance of other minerals, such as mica, or, more rarely, feldspar, which in rare cases may even form the predominating mineral. Pyrite is occasionally present, and varying amounts of clay frequently occur between the grains, at times in sufficient quantity to materially influence the hardness and dressing qualities of the stone. The hardness of sandstones, however, usually depends on the amount and character of the cement, varying from those having so small an amount of silica or iron oxide cement that the stone crumbles in the fingers to those quartzites whose grains are so firmly bound by silica that the rock resembles solid quartz. With these differences the chemical composition varies from nearly pure silica to sandstone with a large percentage of other compounds. (For analyses, see Kemp's " Handbook of Rocks.")

There are many colors among sandstones, but light gray, white, brown, buff, bluish gray, red, and yellow are most common. In density sandstones range from the nearly impervious quartzites to the porous sandrocks of recent geologic formations, and consequently they show a variable absorption. Most sandstones contain some quarry water, and those with appreciable amounts are softer and more easy to dress when first quarried; but they cannot be quarried in freezing weather. The average specific gravity of sandstone is 2.7, and accordingly a cubic foot weighs about 160 to 170 pounds.

On the whole, sandstones resist heat well and are usually of excellent durability, since they contain few minerals that decompose easily. When they disintegrate, it is commonly by frost action. The injurious minerals are pyrite, mica, and clay. Pyrite is likely to cause discoloration on weathering; the presence of much mica may cause the stone to scale off if set on edge; and clay may cause injury to the stone in freezing weather on account of its capacity for absorbing moisture. A slight quantity of clay, however, makes

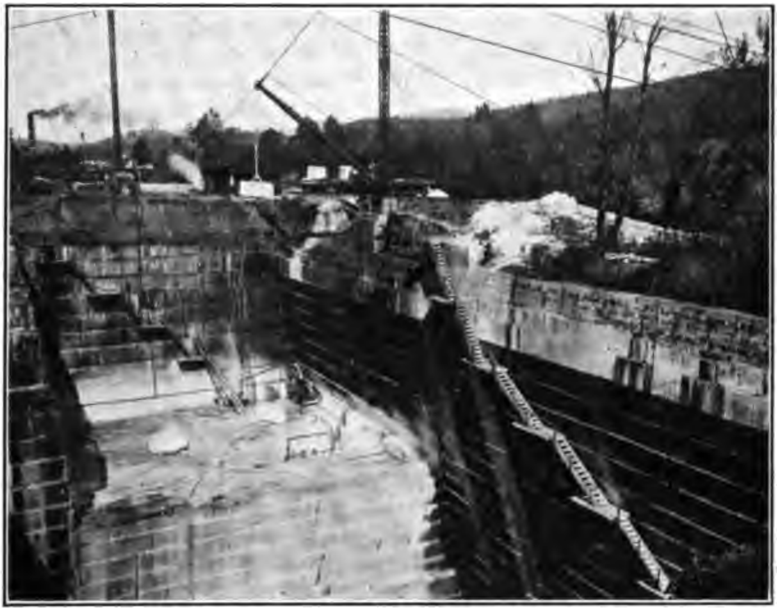

FIG. 1. — Marble quarry, Pickens County, Ga. (*Photo. loaned by S. W. McCallie.*)

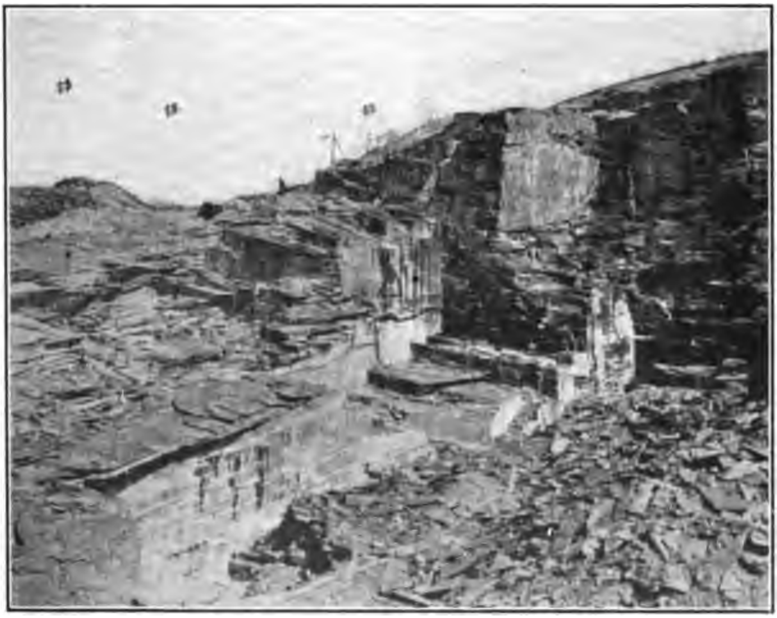

FIG. 2. — Slate quarry at Penrhyn, Pa. (*H. Ries, photo.*)

the stone easier to dress. The value of a standstone is often lessened by careless quarrying, or by placing it on edge in the building, thus exposing the bedding planes to the entrance of water.

Varieties of Sandstone. — With an increase in the size of their grains, sandstones pass into conglomerates on the one hand and with an increase in clay into shales. By an increase in the percentage of carbonate of lime they may also grade into limestones.

On account of these variations, as well as the difference in color and the character of the cement, a number of varieties of sandstone are recognized, of which the following are of economic value: *arkose*, a sandstone composed chiefly of feldspar grains; *bluestone*, a flagstone much quarried in New York; *brownstone*, a term formerly applied to sandstones of brown color, obtained from the eastern Triassic belt, and since stones of other colors are now found in the same formation, the term has come to have a geographic meaning and no longer refers to any specific physical character; *flagstone*, a thinly bedded, argillaceous sandstone used chiefly for paving purposes; *freestone*, a sandstone which splits freely and dresses easily.

Distribution of Sandstones in the United States. — Sandstones occur in all formations from pre-Cambrian to Tertiary. They are so widely distributed that for local supply there are numerous small quarries in many states, but there are several areas which have been operated on an extensive scale, some of them for many years. Of these, one of the best known is the Triassic Brownstone belt, which extends from the Connecticut Valley, in Massachusetts, southwestward into North Carolina.

This is a red, brown, or even bluish sandstone, of moderate hardness, and somewhat variable texture. That from the Connecticut Valley district was formerly used in enormous quantities.

Among the Paleozoic strata there are many sandstones, often massive, and usually dense and hard. Of these the Medina and Potsdam are specially important and much quarried in New York State (34, 35). The same formations extend southward along the Appalachians and are available at several points. Devonian flagstones are extensively quarried at several localities in New York and Pennsylvania. At the present time the Lower Carboniferous Berea sandstone of Ohio (37) is in great demand because of its light color, even texture, and the ease with which it is worked. Moreover, it has the peculiar property of changing to a uniform buff on exposure to the air. There are numerous other Paleozoic sandstones in the central states, among them the Potsdam, which covers a wide area in Michigan and Wisconsin (51). Some of this stone is bright red in color.

The Mesozoic and Tertiary strata of the West contain an abundance of good sandstone, and quarries opened in many of them yield a durable quality of stone. Though usually less dense and hard than the Paleozoic sandstones, they serve admirably for buildings in the mild or dry climates of the West.

Uses of Sandstones.—The wide distribution of sandstones makes them an important source of local structural material. They are chiefly used for ordinary building work, and but little for massive masonry or monuments. The thin-bedded flagstones are much used for flagging, and some of the harder sandstones are split up for paving blocks. For other uses, see Abrasives.

SLATES

General Characteristics (3, 43*a*).—Slates are metamorphic rocks derived from clay or shale or more rarely from igneous rocks (14). Their value depends upon the presence of a well-defined plane of splitting, called *cleavage* (Fig. 47), developed by metamorphism through the rearrangement and flattening of the original mineral grains and the development of micaceous minerals. The cleavage usually develops at a variable angle to the bedding planes which are often completely obliterated by the metamorphism. When not completely destroyed, the bedding planes are marked by parallel bands, called ribbons, cutting across the planes of cleavage, but so perfect is the cleavage in the best slates that the rock readily splits into thin sheets with a smooth surface.

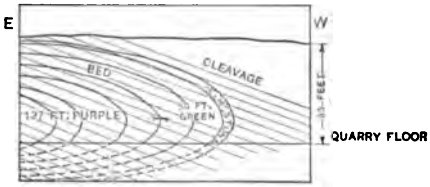

FIG. 47.—Section showing cleavage and bedding in slate. (*After Dale, U. S. Geol. Surv., 19th Ann. Rept., III.*)

Slates are commonly so fine grained that the mineral composition is not evident to the eye, but the microscope reveals the presence of many of the varied mineral grains found in shale, and in addition much chlorite, developed by metamorphism. Owing to the presence of carbonaceous particles, most slates are black or bluish black, but green, purple, and red slates are also known. The specific gravity of slate is about 2.7, and a cubic foot weighs between 170 and 175 pounds.

Most slates are fairly durable, though the presence of pyrite along the ribbons may lead to their decay. Lime carbonate if present in any quantity is injurious, and if the slate is to be used for switchboards, it should be as free from magnetite grains as possible. Some colored slates fade on exposure to the weather, but this change, which is due to the bleaching of certain mineral grains, does not necessarily result in loss of strength or disintegration.

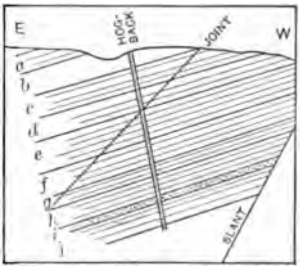

FIG. 48. — Section in slate quarry with cleavage parallel to bedding. *a*, purple slate; *b*, unworked; *c* and *d*, variegated; *e* and *f*, green; *g* and *h*, gray-green; *i*, quartzite; *j*, gray with black patches. (*After Dale.*)

In slate quarrying it is of importance to distinguish between bedding and cleavage. The following criteria may be used (43*a*). Quartzite and limestone bands of some persistence indicate bedding, but care must be taken not to mistake vein quartz for quartzite. Fossil impressions are always on the bed surface. A microscopic section, transverse to cleavage, may be used, if other means fail, to indicate divergence between bedding and cleavage, although in some places the two may agree.

Special tests are necessary for determining the quality of slate. They include the determination of its sonorousness, cleavability, abrasive resistance, absorption, elasticity, and presence of injurious minerals. The chemical analysis is of limited value, but Merriman concludes that the strongest slate runs highest in silica and alumina but not necessarily lowest in lime and magnesium carbonates.

Dale divides slates into the following groups:

I. Aqueous sedimentary.
  A. Clay slates: cemented by clay, lime carbonate, or magnesium carbonate. Fissility, strength, and elasticity low.
  B. Mica slates: 1. fading; with sufficient iron carbonate to discolor on exposure. 2. Unfading; without sufficient iron carbonate to produce any but very slight discoloration on prolonged exposure.
  Under each group we may have the following types: Graphitic (gray-black); chloritic (greenish); hematitic and chloritic (purplish). The second group may also include hematitic (reddish).
II. Aqueous.
  A. Ash slates.
  B. Dike slates.

Distribution of Slates in the United States (Fig. 49). — Since slates are of metamorphic origin, they are limited to those regions in which the rocks are metamorphosed, and at present the greater part of our supply comes from the Cambrian and Silurian strata of the eastern crystalline belt of the Atlantic states.

A series of quarries producing red, green, purple, and variegated slates are located in a belt of Cambrian and Hudson River strata along the border of New York (33) (Pl. XVI) and Vermont (33, 45).

Black slates are quarried in Maine (3), New Jersey (32), Pennsylvania (3), (Pl. XV., Fig. 2), Maryland (26), Georgia (3), and Virginia (46). Other producing states are Minnesota, California (14, 43*a*), and Arkansas (12).

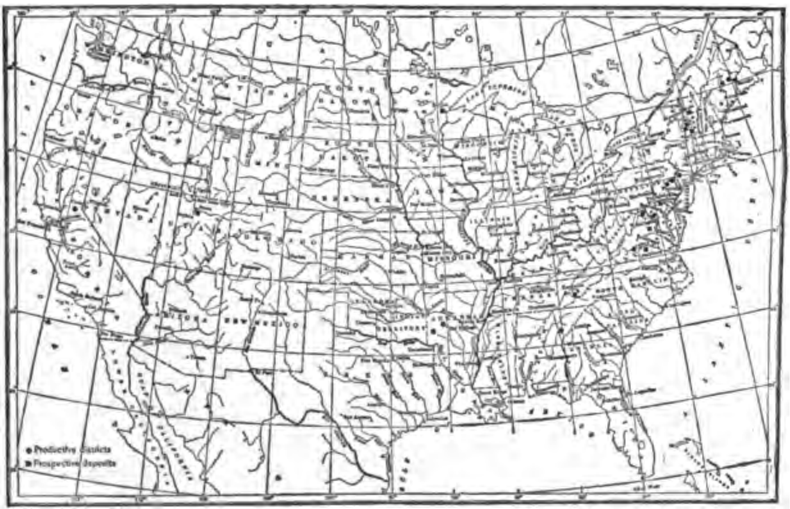

FIG. 49. — Map showing distribution of slate in the United States. (*After Dale, U. S. Geol. Surv., Bull.* 275.)

Uses of Slate. — Slate is best known as a roofing material, but it is also used for mantels, billiard-table tops, floor tiles, steps, flagging, slate pencils, acid towers, washtubs, etc. The process of marbleizing slates for mantles and fireplaces is carried on at several localities.

In quarrying slate there is from 40 to 60 per cent waste, which is greater than in any other building stone; but the introduction of channeling machines in quarrying has done much to reduce this. The discovery of a use for this waste has been an important problem, which has thus far been only partially solved. It is sometimes ground for paint, and attempts have been made to utilize it in the manufacture of bricks and Portland cement.

Production of Building Stones. — The production of building stones by kinds for the last 5 years was as follows: —

Plate XVI. — View of green-slate quarry, Pawlet, Vt. (*Photo. by H. Ries.*)

Production of Building Stones in the United States from 1904 to 1908

Kind	1904	1905	1906	1907	1908
Granite	$17,191,479	$17,563,139	$18,562,806	$18,064,708	$18,420,080
Trap Rock	2,823,546	3,074,554	3,736,571	4,594,103	4,282,406
Sandstone	8,482,162	8,075,149	7,147,439	6,753,762	5,831,231
Bluestone	1,791,729	1,931,625	2,021,898	2,117,916	1,762,860
Marble	6,297,835	7,129,071	7,582,938	7,837,685	7,733,920
Limestone	22,178,964	26,025,210	27,327,142	31,737,631	27,682,002
Total	$58,765,715	$63,798,748	$66,378,794	$71,105,805	$65,712,499

It should be noted that the stone statistics compiled by the United States Geological Survey include not only building stone, but stone used for monuments, furnace flux, road material, etc. Some idea of the quantity used for each of these purposes can be gained from the following table:—

Value of Stone used for Different Purposes in 1908

Kind	Building (Rough and Dressed)	Monumental (Rough and Dressed)	Flagstone	Curbstone	Paving Stone	Crushed Stone
Granite	$5,751,258	$4,551,061	$70,744	$942,722	$2,420,554	$2,445,268
Trap Rock	40,543	—	—	—	184,125	4,002,220
Sandstone	2,605,381	—	1,067,334	1,025,259	654,896	906,317
Limestone	4,566,522	—	79,081	237,579	276,637	12,908,207
Marble	3,076,926	2,397,780	—	—	—	—
	$16,040,630	$6,948,841	$1,217,159	$2,205,560	$3,536,212	$20,262,012

The value of the building stones produced by the several more important states, together with the kind of stone produced chiefly in 1908, is given below:—

Production of Building Stones in more Important States in 1908

State	Total Value	Kind produced chiefly	Per Cent of Total U. S. Stone Production
Vermont	$7,152,624	Marble	10.88
Pennsylvania	6,371,152	Limestone	9.70
New York	6,157,279	Limestone	9.37
Ohio	4,764,309	Limestone	7.26
Indiana	3,646,603	Limestone	5.55
California	3,291,585	Granite	5.01
Illinois	3,134,770	Limestone	4.77
Massachusetts	2,955,195	Granite	4.50
Wisconsin	2,850,920	Granite	4.34
Missouri[1]	2,306,058	Limestone	3.51
Maine[1]	2,027,508	Granite	3.09
Georgia	1,895,608	Granite	2.88
New Jersey	1,531,740	Trap Rock	2.33
Minnesota	1,493,706	Limestone	2.27

[1] Not the entire output.

The order of rank is but little different from that of 1907, although Pennsylvania dropped to second place, because of decreased demand for limestone used for fluxing purposes in the steel industry.

Exports and Imports. — The following figures show the value of the exports and imports for the years 1907 and 1908: —

EXPORTS OF STONE FROM THE UNITED STATES IN 1907 AND 1908

KIND	1907	1908
Marble and stone, unmanufactured	$407,193	$249,184
All others	681,798	754,067
	$1,088,991	$1,003,251

IMPORTS OF STONE INTO THE UNITED STATES IN 1907 AND 1908

KIND	1907	1908	KIND	1907	1908
Marble:			Granite:		
In block, rough, etc.	$1,040,333	$831,099	Dressed	$166,524	$187,229
Sawed or dressed	1,132	2,428	Rough	8,779	6,384
Slabs or paving tiles	50,718	89,371	Total	$175,303	$193,613
All other manufactures	257,456	180,751	Stone (other)		
Mosaic cubes	49,893	35,053	Dressed	26,003	12,345
Total	$1,399,532	$1,138,702	Rough	38,761	56,565
Onyx:			Total	$64,764	$68,910
In block, rough, etc.	$57,795	$71,979	Grand total	$1,705,072	$1,483,026
All other manufactures	7,678	9,822			
Total	$65,473	$81,801			

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CHAPTER IV

CLAY

Definition. — Clay, which is one of the most widely distributed materials and one of the most valuable commercially, may be defined as a fine-grained mixture of the mineral *kaolinite* (the hydrated aluminum silicate) with fragments of other minerals, such as silicates, oxides, and hydrates, and also often organic compounds, the mass possessing plasticity when wet and becoming rock hard when burned to at least a temperature of redness.

Two important classes of clays are the residual and the transported ones.

Residual Clays (8). — Clays are derived primarily and principally from the decomposition of crystalline rocks, more especially feldspathic varieties, and deposits thus formed will be found overlying the parent rock and often grading down on to it. From its method of origin and position it is termed a *residual clay* (Fig. 50).

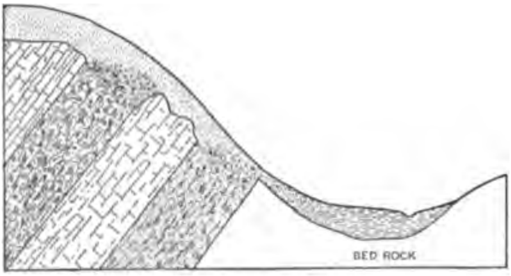

Fig. 50. — Section showing formation of residual clay. (*After Ries, U. S. Geol. Surv., Prof. Pap.* 11.)

All residual clays probably contain a variable amount of kaolinite (8) or clay substance. This mineral, which is white in color, results from the decomposition of feldspar, either by weathering, or, less often, by the action of volcanic vapors. The decay of a large mass of pure feldspar would therefore yield a mass of white clay, but, in most instances, the feldspar is associated with other minerals, such as quartz, mica, and hornblende, all of which, except the quartz, decay with greater or less rapidity, and some of these, such as the hornblende, may likewise yield a hydrous aluminum silicate. Any ferruginous minerals in the rock will, in decomposing, yield limonite, which stains the mass.

Large masses of pure feldspar are rare, but feldspathic rocks, such as granite or syenite, are more common, and these will also decompose to clay; but, since the parent rock contains other minerals, such as quartz or mica, these will either remain as sand grains in the clay, or, by decomposition, will form soluble compounds, or iron stains. The decay of many rocks, for example, limestone and shale, in addition to the crystalline rocks, produces a residuum of clay. White-burning residual clays are termed kaolins, but they are rare.

The extent of a deposit of residual clay will depend on the extent of the parent rock and the topography of the land, which also influences its thickness. On steep slopes much of the clay may be washed away; and residual clays are also rare in glaciated regions, for the reason that they have been swept away by the ice erosion. They are consequently wanting in most of the Northern states, but abundant in many parts of the Southern states, where the older formations appear at the surface.

Transported Clays (8). — With the erosion of the land surface the particles of residual clay become swept away to lakes, seas, or the ocean, where they settle down in the quiet water as a fine aluminous sediment, forming a deposit of *sedimentary clay* (Fig. 51). Such beds are often of great thickness and vast extent. With the accumulation of many feet of other sediments on top of them, they become consolidated either by pressure or by the deposit of a cement around the grains. Consolidated clay is termed *shale*, and this upon being ground and mixed with water often becomes as plastic as an unconsolidated clay.

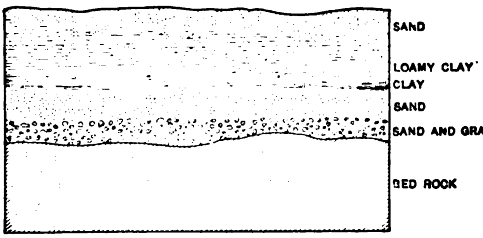

FIG. 51. — Section of a sedimentary clay deposit. (*After Ries, U. S. Geol. Surv., Prof. Pap.* 11.)

Residual materials may also have been transported by wind or glacial action, to form clayey deposits.

The following are important types of transported clays: —

Marine Clays. — Formed by the deposition on the ocean floor of the finer particles derived from the waste of the land. Such ancient sea-bottom clays have been elevated to form dry land in all the continents, in many cases forming consolidated clay strata, but elsewhere, especially in coastal plains, in unconsolidated condition. Extensive clay deposits are also formed in protected estuaries and lagoons along the seacoast.

Flood-plain Clays. — Formed by the deposition of clayey sediment on the lowlands bordering a river during periods of flood. Layer upon layer, this deposit builds a flood plain often of great extent and depth. Such areas of flood-plain clays are most extensive along the greater rivers and in the deltas which they have built in the sea.

Lake Clays. — Clay is deposited on the bottom of many lakes and ponds in the same manner as on the ocean bottom. Where the streams bring only fine particles the filling of a lake may be entirely of clay. Many lakes have been either drained or completely filled and their clays therefore made available. This is especially true of small, shallow lakes formed during the Glacial Period.

Glacial Clays, commonly known as till or bowlder clay, a rock flour ground in the glacial mill in which rock fragments were worn down to clay by being rubbed together or against the bed rock over which the ice moved. When the ice melted, this deposit was left in a sheet of varying thickness and characteristics over a large part of the area which the ice covered. It is not always, strictly speaking, a sedimentary deposit.

Æolian Clays. — Wind drifts dry clay about, and in favorable positions causes its accumulation in beds. This is true of the Chinese loess, a wind-blown deposit derived from residual soils and drifted about in the arid climate of interior China. Some at least of the loess clays of the Mississippi Valley seem to have a similar origin, the source of the clay being glacial deposits; in other cases loess seems to be a water deposit either in shallow lakes or else in broad, slowly moving streams.

Properties of Clay. — These are of two kinds, physical and chemical, and since they exercise an important influence on the behavior of the clay, the most important ones may be described.

Physical Properties (8, 1). — These include plasticity, tensile strength, air and fire shrinkage, fusibility, and specific gravity.

Plasticity may be defined as the property which clay possesses of forming a plastic mass when mixed with water, thus permitting it to be molded into any desired shape, which it retains when dry. This is an exceedingly important character of clay. Clays vary from exceedingly plastic, or "fat" ones, to those of low plasticity which are "lean" and sandy. Plasticity is probably due in part to fineness of grain, and in part to the presence of colloids (1, 8).

Tensile strength is the resistance which a mass of air-dried clay offers to rupture, and is probably due to interlocking of the particles. Tests show that the tensile strength of clays varies from 15 to 20 pounds per square inch up to 400 pounds or more per square inch. Many common brick clays range from 100 to 200 pounds.

Shrinkage is of two kinds — air shrinkage and fire shrinkage. The former takes place while the clay is drying after being molded, and is due to the evaporation of the water, and the drawing together of the clay particles. The latter occurs during firing, and is due to a compacting of the mass as the particles soften under heat. Both are variable. In the manufacture of most clay products an average total shrinkage of about 8 or 9 per cent is commonly desired. Excessive air or fire shrinkage causes cracking or warping of the clay. To prevent this a mixture of clays is often used.

Fusibility is one of the most important properties of clays. When subjected to a rising temperature, clays, unlike metals, soften slowly, and hence fusion takes place gradually. In fusing, the clay passes through three stages, termed, respectively, incipient fusion, vitrification, and viscosity.

In the lower grades of clay, that is, those having a high percentage of fluxing impurities, incipient fusion may occur at about 1000° C., while in refractory clays, which are low in fluxing impurities, it may not occur until 1300° or 1400° C. is reached. The temperature interval between incipient fusion and vitrification may be as low as 30° C. in calcareous clays, or as much as 200° C. in some others. The recognition of this variation is of considerable practical importance, and vitrified products, such as paving bricks and stoneware, have to be made from a clay in which the three stages of fusion are separated by a distinct temperature interval. The importance of this rests on the fact that it is impossible to control the temperature of a large kiln within a few degrees, and there must be no danger of running into a condition of viscosity in case the clay is heated beyond its point of vitrification.

Specific gravity varies commonly from about 1.70 to 2.30.

Chemical Properties (8). — The number of common elements which have been found in clays is great, and even some of the rarer ones have been noted; but in a given clay the number of elements present is usually small, being commonly confined to those determined in the ordinary chemical analyses, which show their existence in the clay, but not always the state of the chemical combination. The common constituents of a clay are silica, alumina, ferric or ferrous oxide, lime, magnesia, alkalies, titanic acid, and combined water. Organic matter, and sulphur trioxide, though often present, are usually in small amounts. Carbon dioxide is always found in calcareous clays. The effect of these may be noted briefly.

Silica is most often present in the form of quartz grains; but it may also be contained in grains of undecomposed minerals. It aids in lowering the plasticity and shrinkage, and helps to increase the refractoriness at low temperatures. A clay high in silica (70 to 80 per cent) is usually sandy. *Alumina*, which is most abundant in white clays, is a refractory ingredient. *Iron oxide* acts as a coloring agent in both the raw and burned clay, small quantities usually coloring a burned clay buff, and larger amounts (4 to 7 per cent), if evenly distributed, turning it red. It also acts as a flux in burning. Whatever the iron compound present in the raw clay it changes to the oxide in burning. *Lime*, *magnesia*, and *alkalies* are also fluxing ingredients of the clay. The combined percentage of fluxing impurities is small in a refractory clay, and often high in a low-grade one. Lime, if present in considerable excess over the iron, will, in burning, exert a bleaching effect on the latter. For this reason, highly calcareous clays, such as those in the Great Lake region, burn cream or buff. When lime is present in large amounts, it also causes clay to soften more rapidly in firing than it otherwise would.

Chemically combined water and organic matter both pass off at a temperature of very dull redness (450° to 650° C.). Their loss leaves the clay temporarily porous until fire shrinkage sets in. *Titanic acid*, though rarely exceeding 1 per cent, acts as a flux at high temperatures at least. *Sulphur trioxide* is rarely present in sufficiently high amounts to interfere with the successful burning of the clay.

Carbon colors a raw clay gray or black, and several per cent may give much trouble in burning, unless driven out of the clay before it becomes dense.

Chemical Composition. — As might be expected from their diverse modes of origin, clays vary widely in their chemical composition. There is every gradation from those which, in composition, closely resemble the mineral kaolinite, to those, like ordinary brick clays, in which there is a high percentage of impurities. This variation is shown in the opposite table.

The absence of ferrous oxide, titanic oxide, sulphur trioxide, organic matter, and manganous oxide in many of the analyses (p. 129) does not necessarily indicate their non-existence in these clays. Probably all contain at least small percentages of these substances, but they are rarely determined.

Classification of Clay. — It is possible to base a classification of clays either on origin, chemical and physical properties, or uses. But since the subdivisions which can be made are not sufficiently distinct, each of these gives rise to a more or less unsatisfactory grouping. The following classification is based partly on mode of origin and partly on physical characters (8): —

A. Residual clays. (By decomposition of rocks *in situ.*)
  I. Kaolins or china clays (white-burning).
    (*a*) Veins, derived from pegmatite, rhyolite, etc.
    (*b*) Blanket deposits, derived from extensive areas of igneous or metamorphic rocks.
    (*c*) Pockets in limestone, as indianaite (24).
  II. Red-burning residuals, derived from different kinds of rocks.
B. Colluvial clays, representing deposits formed by wash from the foregoing, and of either refractory or non-refractory character.
C. Transported clays.
  I. Deposited in water.
    (*a*) Marine clays or shales. Deposits often of great extent.
      White-burning clays. Ball clays and plastic kaolins.
      Fire clays or shales. Buff-burning.
      Impure clays or shales. { Calcareous. Non-calcareous.
    (*b*) Lacustrine clays (deposited in lakes or swamps).
      Fire clays or shales.
      Impure clays or shales, red-burning.
      Calcareous clays, usually of surface character.
    (*c*) Flood-plain clays. Usually impure and sandy.
    (*d*) Estuarine clays (deposited in estuaries). Mostly impure and finely laminated.

ANALYSES SHOWING VARIATION IN COMPOSITION OF CLAYS

	I	II	III	IV	V
Silica (SiO_2)	46.3	45.78	57.62	59.92	68.62
Alumina (Al_2O_3)	39.8	36.46	24.00	27.56	14.98
Ferric oxide (Fe_2O_3)	—	.28	1.9	1.03	4.16
Ferrous oxide (FeO)	—	1.08	1.2	—	—
Lime (CaO)	—	.50	.7	tr	1.48
Magnesia (MgO)	—	.04	.3	tr	1.09
Potash (K_2O)	—	.25	.5	.64	3.36
Soda (Na_2O)	—		.2		
Titanic oxide (TiO_2)	—	—	—	—	—
Water (H_2O)	13.9	13.40	10.5	9.70	3.55
Moisture	—	2.05	2.7	1.12	2.78
Carbon dioxide (CO_2)	—	—	—	—	—
Sulphur trioxide (SO_3)	—	—	.35	—	—
Organic matter	—	—	—	—	—
Manganous oxide (MnO)	—	—	—	—	.64
Total	100.00	99.84	99.97	99.97	100.66

	VI	VII	VIII	IX	X
Silica (SiO_2)	82.45	54.64	38.07	90.00	47.92
Alumina (Al_2O_3)	10.92	14.62	9.46	4.60	14.40
Ferric oxide (Fe_2O_3)	1.08	5.69	2.70	1.44	3.60
Ferrous oxide (FeO)	—	—	—	—	—
Lime (CaO)	.22	5.16	15.84	.10	12.30
Magnesia (MgO)	.96	2.90	8.50	.10	1.08
Potash (K_2O)	—	5.89	2.76	tr.	1.20
Soda (Na_2O)				tr.	1.50
Titanic oxide (TiO_2)	1.00	—	—	.70	1.22
Water (H_2O)	2.4	3.74	2.49	3.04	4.85
Moisture	—	.85		—	—
Carbon dioxide (CO_2)	—	4.80	20.46	—	9.50
Sulphur trioxide (SO_3)	—	—	—	—	1.44
Organic matter	—	—	—	—	1.34
Manganous oxide (MnO)	—	.76	—	—	—
Total	99.03	99.05	100.28	99.98	100.35

I. Kaolinite.
II. Washed kaolin, Webster, N. Ca.
III. Plastic fire clay, St. Louis. Mo.
IV. Flint fire clay, Salineville, O.
V. Loess clay, Guthrie Center, Ia.
VI. Pressed-brick clay, Rusk, Tex.
VII. Brick shale, Mason City, Ia.
VIII. Calcareous brick clay, Milwaukee, Wis.
IX. Sandy brick clay, Colmesneil, Tex.
X. Blue shale clay. Ferris, Tex.

    - II. Glacial clays, found in the drift, and often stony. May either be red- or cream-burning.
    - III. Wind-formed deposits (some loess).
- D. Chemical deposits (some flint clays?).

Kinds of Clays. — Many kinds of clays are known by special names, which in some cases indicate their use, but in others refer partly to certain physical properties. The more important ones are the following: —

Adobe. A sandy, often calcareous, clay used in the west and southwest for making sun-dried brick. *Ball clay.* A white-burning, plastic, sedimentary clay, employed by potters to give plasticity to their mixture. *Brick clay.* Any common clay suitable for making ordinary brick. *China clay.* A term applied to kaolin (*q.v.*). *Earthenware clay.* Clay suitable for the manufacture of common earthenware, such as flower pots. *Fire clay.* A clay capable of resisting a high degree of heat. *Flint clay.* A peculiar flint-like fire clay, which when ground up and wet develops no plasticity. Chemically, it differs but little, if at all, from the plastic fire clays. Moreover, the two often occur in the same bed, either in separate layers or irregularly mixed. *Gumbo.* A very sticky, highly plastic clay, occurring in the central states, and used for making burned-clay ballast (2). *Kaolin.* A white-burning residual clay, employed chiefly in manufacture of white earthenware and porcelain. The term is also applied by some to the white-burning sedimentary clays of Georgia and South Carolina. *Loess.* A sandy, calcareous, fine-grained clay, covering thousands of square miles in the central states, and of wide use in brick making. *Paper clay.* Any fine-grained clay, of proper color, that can be employed in the manufacture of paper. *Pipe clay.* A loosely used term applied to any smooth plastic clay. Strictly speaking, it refers to a clay suited to the manufacture of sewer pipe. *Pot clay.* A dense-burning fire clay, used in the manufacture of glass pots. The domestic supply comes mainly from St. Louis, Missouri, but much is imported. *Pottery clay.* Any clay suitable for the manufacture of pottery. *Retort clay.* A plastic fire clay, used in making gas retorts. The term is a local one used chiefly in New Jersey. *Sagger clay.* A loose term applied to clays employed in making saggers; they are of value for other purposes as well. *Sewer-pipe clay.* A term applicable to any clay that can be used for manufacture of sewer-pipe. It is usually vitrifiable and red-burning. *Slip clay.* Under this term are included those clays which are easily fusible, and form a natural glaze, when applied to ware (such as stoneware) and burned at the proper temperature. The best-known variety comes from Albany, N. Y. *Stoneware clay.* A very plastic clay, which burns to a vitrified or stoneware body. It may be refractory. *Terra-cotta clay.* Clay suitable for the manufacture of terra cotta. The term has no special significance, as a wide variety of clays are adapted to this purpose.

Geological Distribution. — Clays have a wider distribution than most other economic minerals or rocks, being found in all forma-

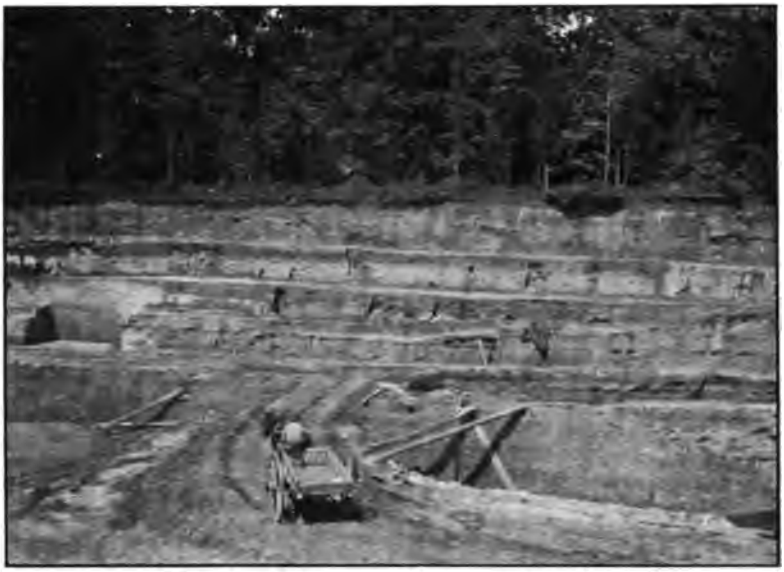

Plate XVII. — Bank of sedimentary clay, Woodbridge, N. J. This section affords at least five kinds of clay. (*Photo., H. Ries.*)

tions from the oldest to the youngest. The pre-Cambrian crystallines yield both white and colored residual clays, usually the result of weathering, though more rarely of solfataric action. In the Paleozoic rocks, deposits of shale, and sometimes of clay, are found in many localities; and, since they are usually marine sediments, the beds are often of great extent and thickness. The weathered outcrops of these may yield a residual clay. With the exception of certain Carboniferous deposits, the Paleozoic clays are mostly impure. The Mesozoic formations contain large supplies of clays and shale suitable for the manufacture of bricks, terra cotta, stoneware, fire brick, etc.

The Pleistocene clays are all surface deposits, usually impure, and individually of limited extent, although they are thickly scattered all over the United States. Their chief value is for brick and tile making. They have been accumulated by glacial action, on flood plains, in deltas, or in estuaries and lakes.

Distribution of Clays by Kinds. — *Kaolins* (67). — Since kaolins proper are derived only from crystalline or igneous rocks, their distribution is limited; indeed, at present the only deposits worked are in the eastern states. Being commonly formed by the weathering of pegmatite veins, kaolin deposits have great length as compared with their width, which may be anywhere from 5 to 300 feet. Their depth ranges from 20 to 120 feet, depending on the depth to which the feldspar has been weathered.

	CRUDE KAOLIN	WASHED KAOLIN
SiO_2	62.40	45.78
Al_2O_3	26.51	36.46
Fe_2O_3	1.14	.28
FeO	—	1.08
CaO	.57	.50
MgO	.01	.04
Alkalies	.98	.25
H_2O	8.80	13.40
Moisture	.25	2.05
	100.66	99.84
Clay substance	66.14	93.24

Quartz and white mica are often present in kaolin, and it is then frequently necessary to put the clay through a washing process to remove these minerals. The difference between a washed and unwashed kaolin is well shown by the two preceding analyses, from which it is seen that the quartz contents have been considerably lowered, and that the washed product approaches more closely to the composition of kaolinite.

North Carolina (52) and Pennsylvania (58, 56) are the most important residual kaolin-producing states, but deposits are also worked in Connecticut (17 *a*), Maryland (36), and Virginia (67). It is known to occur in Alabama (10). All of these deposits except that in Connecticut are found south of the limit of the glacial drift. Kaolins occur in southeastern Missouri, but they have never become of great importance (45).

The Cretaceous of Georgia (20) and South Carolina contains important deposits of white-burning sedimentary clays, which might perhaps be termed plastic kaolins to distinguish them from the residual ones.

The output from the American deposits is insufficient to supply the domestic clay-working industry, and consequently many thousand tons are annually imported from England. Since this can be brought over as ballast, it is possible to put it on the American market at a low price. The best grades of kaolin sell for $10 to $12 per ton at Trenton, New Jersey, and East Liverpool, Ohio, these being the two most important pottery centers of this country.

Fire Clays. — Fire clays are found in the rocks of all systems, from the Carboniferous to the Tertiary, inclusive, with the exception of the Triassic.

The most extensive, and among the most important, beds of fire clay are those found in the Carboniferous strata of Pennsylvania (56, 60), Ohio (54, 55), Kentucky (29, 30, 33), West Virginia (72), Maryland (36), Indiana (24), Missouri (45), and Illinois (21, 22). Those of the first two named states are on the average the most refractory. Here the fire clays are usually found underlying coal seams and often at well-marked horizons, especially in the Upper Productive Measures.

The section given in Fig. 2 is fairly representative of their mode of occurrence.

Those of Indiana and Illinois are so placed that one mine shaft may be used for extracting coal, fire clay, stoneware clay, and shale.

The beds of refractory clay, found in the Carboniferous strata near St. Louis (45), are not only used in the manufacture of fire brick, but are, in some cases, found suitable, after washing, for mixture with imported German clays for the manufacture of glass pots.

In the Lower Cretaceous of New Jersey (49) there are many beds of refractory clay, variable in thickness and closely associated with beds of less refractory character. They not only support a thriving local fire-brick industry, but serve also as a source of supply for factories in other states. Similar, but less extensive and less refractory, beds occur in strata of Cretaceous Age in the coastal plain of Maryland (36), Georgia (20), South Carolina (61), and Alabama (10).

The Tertiary formations of Texas (64) and Mississippi (44) hold abundant deposits of refractory material, but many are undeveloped. The Missouri Tertiary also supplies some fire clays (45).

Fire clays are found in the Black Hills of South Dakota (62), in the Laramie beds of Colorado (14–17), and in California (13); but, excepting near Denver, where used for making fire brick and assayer's apparatus, these deposits are as yet slightly developed.

Pottery Clays. — Under this heading are included several grades of clay, the kaolins, already described, being the purest and best suited to the manufacture of high grades of pottery.

Another high-grade pottery clay of more plastic character, the ball clay, is of limited distribution in the United States. A small quantity is found in the Cretaceous (Pl. XVII) of New Jersey (49), and a much larger amount in the Tertiary of western Kentucky (29, 31) and Tennessee (63), and southeastern Missouri (45) and Florida (19, 67). As in the case of kaolin, the domestic supply is not sufficient to meet the demand, and large quantities of ball clay are imported from England.

Stoneware clays form a third grade of pottery clays. They are usually of at least semirefractory character, but differ from fire clays proper in burning dense at a much lower temperature. Their distribution is essentially coextensive with that of fire clays; indeed, the two are often dug from the same pit or mine. Large quantities are obtained in the Carboniferous of western Pennsylvania (56, 57) and eastern Ohio (55) and smaller amounts in the New Jersey Cretaceous formations (49).

Stoneware clays, usually in the same area as the fire clays, are also obtained in Illinois (21), Indiana (24), Kentucky (29, 31), Tennessee (63), Alabama (10), and Texas (64); and they occur also in Missouri (45), Iowa (26), Colorado (15), and California (13).

Many of the Pleistocene surface clays in various states are sufficiently dense-burning to be used locally by small stoneware factories.

Brick and Tile Clays (67). — None of our states lack an abundant supply of good brick and tile clays, and in many areas there are extensive deposits near the large markets, and often near tide water. In such cases the clay beds are exploited to an enormous extent.

In the northeastern states the Pleistocene surface clays are found almost everywhere in great abundance, and are made use of in many places, especially near the large cities.

In the middle Atlantic states Columbian loams and clay marls are an important source of brick material.

In Ohio, Illinois, and Indiana Pleistocene clays, in part of glacial, and in part of flood-plain origin, are much used for brick and tile. Impure Paleozoic shales are also used in places, especially in the manufacture of vitrified paving brick, thousands of which are made annually in Ohio. Northern Illinois, Michigan, and Wisconsin draw their main supply of brick clays from the calcareous lake deposits.

Although glacial clays and flood-plain deposits are much used in the states west of the Mississippi, the loess which occurs over a wide area is probably even more important as a source of brick, while in the southwestern states loess and adobe are important. Residual clays, river silts, glacial clays, and other forms of clay are employed in brick making along the Pacific coast.

Miscellaneous Clays of Importance. — Paper clays of good quality are much sought for by paper manufacturers. Much English kaolin is used for this purpose, but the domestic kaolins are also drawn upon, especially those of Georgia, South Carolina, North Carolina, southeastern Pennsylvania, and Connecticut. A small amount of *glasspot clay* (45) comes from western Pennsylvania, but much more from eastern Missouri, and our chief supply is imported. Terra-cotta clays are obtained from the same areas that supply fire clays, New Jersey being the principal producer.

Uses of Clay. — So few people have even an approximate idea of the uses to which clays are put that it seems desirable to call attention to them briefly. In the following table an attempt has been made to do this:[1] —

Domestic. — *Pottery of various grades; Polishing brick,* often known as *bath bricks; Fire kindlers; Majolica stoves.*

Structural. — *Brick; Tiles and Terra cotta; Chimney pots; Chimney flues; Door knobs; Fireproofing; Copings; Fence posts.*

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[1] Table compiled by R. T. Hill and modified by the author.

Hygienic. — *Closet bowls; Sinks,* etc.; *Sewer pipes; Ventilating flues; Foundation blocks; Vitrified bricks.*

Decorative. — *Ornamental pottery; Terra cotta; Majolica; Garden furniture.*

Minor Uses. — *Food adulterants; Paint filler; Paper filling; Electrical insulations; Pumps; Filling cloth; Scouring soap; Packing horses' hoofs; Chemical apparatus; Condensing worms; Ink bottles; Ultramarine manufacture; Emery wheels.*

Refractory Wares. — *Crucibles* and *other assaying apparatus; Refractory bricks* of various patterns; *Glass pots.*

Engineering Work. — *Puddle; Portland cement; Railroad ballast; Water conduits; Turbine wheels.*

Production of Clay and Clay Products. — Owing to the fact that clays are usually manufactured by the producer, it is necessary to give the value of the product, no record being kept of value of the raw material.

Value of Clay Products produced by the Nine Leading States, and Total United States Production, 1904–1908

States	1904	1905	1906	1907	1908
Ohio	$25,647,783	$28,303,039	$31,014,165	$30,340,830	$26,622,490
Pennsylvania	16,821,863	19,124,553	21,774,611	20,291,621	14,842,982
New Jersey	13,304,047	16,699,525	17,362,269	16,005,460	12,313,696
Illinois	10,777,447	12,361,786	12,634,181	13,220,489	11,559,114
New York	10,543,070	14,486,347	13,876,607	11,772,874	8,929,224
Indiana	5,902,589	6,499,573	7,158,234	6,858,124	6,740,167
Missouri	5,481,504	6,203,411	6,696,275	6,898,871	5,631,456
California	3,624,734	3,865,147	4,364,230	5,740,537	4,523,745
Iowa	3,460,853	3,392,122	3,469,027	3,728,785	4,069,497
Total	$131,023,248	$149,697,188	$161,032,722	$158,942,369	$133,197,762

Value of Clay Products, by Kinds, in the United States, 1904–1908

Kind	1904	1905	1906	1907	1908
Common brick	$51,786,558	$61,394,383	$61,300,696	$58,785,461	$44,765,614
Vitrified paving brick	7,557,425	6,703,710	7,857,768	9,654,282	10,657,475
Front brick	5,560,131	7,108,092	7,895,323	7,329,360	6,935,600
Ornamental brick	300,233	293,907	207,119	361,243	259,556
Enameled brick	545,397	636,279	773,104	918,173	660,862
Fire brick	11,167,972	12,735,404	14,206,868	14,946,045	10,696,216
Stove linings	not given separately	645,432	743,414	627,647	529,976
Drain tile	5,348,555	5,850,210	6,543,289	6,864,162	8,661,476
Sewer pipe	9,187,423	10,097,089	11,114,967	11,482,845	11,003,731
Architectural terra cotta	4,107,473	5,003,158	5,739,460	6,026,977	4,577,367
Fireproofing	3,629,101	4,098,793	4,586,538	4,250,618	3,168,037
Tile (not drain)	3,023,428	3,647,726	4,634,898	4,551,881	3,877,780
Pottery	25,158,270	27,918,894	31,440,884	30,143,474	25,135,555

Much clay is mined and sold, especially to manufacturers of high-grade clay products who do not own deposits themselves. The value of production of such clays is given below.

Value of Clays mined and Sold in the United States, 1904–1908

Kind	1904	1905	1906	1907	1908
Kaolin	$304,582	$326,835	$369,452	$340,311	$216,243
Paper clay	267,381	307,238	342,708	293,943	310,943
Slip clay	11,942	33,384	31,546	37,925	22,370
Ball clay	142,028	167,212	199,073	195,515	133,770
Fire clay	1,306,053	1,529,468	1,878,011	2,054,698	1,486,139
Stoneware clay	83,904	219,767	150,774	136,576	102,390
Miscellaneous	204,272	184,102	273,692	389,580	328,131
Total	$2,320,162	$2,768,006	$3,245,256	$3,448,548	$2,599,986

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CHAPTER V

LIMES AND CALCAREOUS CEMENTS

Composition of Limestones (2, 43). — Limes and calcareous cements form an important class of economic products, obtained from limestones by heating them to a temperature ranging from that of decarbonation to clinkering. The term *limestone* is applied to one of the main divisions of the stratified rocks so widely distributed, both geologically and geographically, and formed under such different conditions, that its composition varies greatly, this range of variation becoming appreciable from an inspection of the following table, which contains a few selected types: —

	I	II	III	IV	V	VI	VII	VIII
Silica (SiO_2) . . .	.54	2.22	.48	4.9	14.30	15.05	16.99	12.13
Alumina (Al_2O_3) . .	.42	.92	.20	6.5	.70	9.02	5.00	4.17
Ferric oxide (Fe_2O_3) .		.18			.80	1.27	1.79	3.28
Lime (CaO) . . .	54.73	54.08	31.31	27.3	46.50	39.26	23.15	42.04
Magnesia (MgO) .	.19	.10	21.03	14.6	n.d.	1.90	16.60	.44
Sulphur trioxide (SO_3)	—	—	—	—	—	—	—	n.d.
Carbon dioxide (CO_2)	43.22	42.50	46.98	44.8	36.54	32.90	36.47	33.51
Water (H_2O) . . .	—	—	—	—	—	—	—	—
	99.10	100.00	99.99	98.1	98.84	99.40	100.00	95.57

I. Pure limestone, Ilasco, Mo. II. Chalk, Marinas, Cuba. III. Dolomite, E. Canaan, Conn. IV. Magnesian limestone, Clinton, Hunterdon Co., N. J. V. Siliceous limestone for hydraulic lime, Teil, France. VI. Argillaceous (cement rock) limestone, Lehigh district, Pa. VII. Argillaceous magnesian limestone, Milwaukee, Wis. VIII. Clayey chalk.

From this table it will be seen that limestones vary from rocks composed almost entirely of carbonate of lime, or of carbonate of lime and carbonate of magnesia, to others which are high in clayey or siliceous impurities. The presence of such impurities in large quantity usually imparts an earthy appearance to the limestone, and sometimes even gives it a shaly structure.

Marked variations in composition may at times be found even in a single quarry (50), while in other cases a limestone formation may show remarkable uniformity of composition over a wide area.

Changes in Burning (2). — When limestones are calcined or " burned " to a temperature sufficiently high to drive off volatile constituents, such as carbon dioxide, water, and sulphur (in part), or, in other words, to the point of decarbonation, the rock is left in a more or less porous condition. If heated to a still higher temperature, the rock clinkers or fuses incipiently, but the temperature of clinkering depends on the amount of siliceous and clayey impurities in the rock.

Lime (2, 43). — Limestone free from or containing but a small percentage of argillaceous impurities is, by decarbonation, changed to quicklime, a substance which has a high affinity for water, and which, when mixed with water, "slakes," forming a hydrate of lime. This change is accompanied by the evolution of heat and by swelling, and this action becomes the more marked the higher the percentage of lime carbonate in the rock, for the slaking activity is retarded by the presence of magnesia and especially by argillaceous impurities. Limes may, therefore, be divided into " fat " limes and " meager " limes, depending on the rapidity with which they slake and the amount of heat they develop in doing so.

Hydraulic Cements. — With an increase in clayey and siliceous impurities, the burned rock shows a decrease in slaking qualities, and develops hydraulic properties, or sets when mixed with water, and even under the same. Products of this type are termed cements, and owe their hydraulic properties to the formation during burning of silicates and aluminates of lime. On mixing the burned ground rock with water, these take up the latter and crystallize, thereby producing the set of the cement.

Hydraulic cements can be divided into the following classes: Pozzuolan cements, hydraulic limes, natural cements, and Portland cements.

Pozzuolan Cement (2, 53). — This is produced from an uncalcined mixture of slaked lime and a silico-aluminous material, such as volcanic ash or blast-furnace slag.

This process was known to the ancients, and is named from its early use around Pozzuolano, Italy. The composition of an Italian Pozzuolano earth may vary between the following limits:[1] SiO_2, 52–60; Al_2O_3, 9–21; Fe_2O_3, 5–22; CaO, 2–10; MgO, up to 2; alkalies, 3–16; H_2O, up to 12.

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[1] Schoch, Die Moderne Aufbereitung u. Wertung der Mörtel Materialien, Berlin. 1896.

No deposits of volcanic ash, for use in Pozzuolan cement, are worked in the United States, although extensive deposits of the material are known to occur in the Rocky Mountain and Pacific coast states. The reported importation of Japanese volcanic ash to the Pacific coast states[1] may serve to draw attention to the domestic material. The following composition of the Japanese ash does not fall within the limits given above. It is SiO_2, 42.10; Al_2O_3, 25.72; Fe_2O_3, 18.28; CaO, 1.15; MgO, .85; Na_2O and K_2O, 2.20; loss on ignition, 9.70.

The manufacture of slag cement is now carried on at several localities in the United States, and is a growing industry (2).

Hydraulic limes (2) are formed by burning a siliceous limestone to a temperature not much above that of decarbonation. Owing to the high percentage of lime carbonate, considerable free lime appears in the finished product. Hydraulic limes generally have a yellow color, and a gravity of about 2.9. They slake and set slowly, and have little strength unless mixed with sand. This class is of little importance in the United States, although small quantities have, in the last few years, been produced in Maryland, Georgia, and New York. They are, however, of great importance in Europe, and it may be of interest to give a few analyses of the raw material used abroad (2):

Analyses of Hydraulic Lime Rocks

	1	2	3	4
Silica (SiO_2)	14.30	11.03	7.60	17.00
Alumina (Al_2O_3)	.70	3.75	.75	1.00
Iron oxide (Fe_2O_3)	.80	5.07		——
Lime (CaO)	46.50	43.02	50.05	44.80
Magnesia (MgO)	undet.	1.34	.30	.71
Carbon dioxide (CO_2)	36.54	35.27	41.30	35.99
Water				

1. Teil, France. 2. Hausbergen, Germany. 3. Malain, France. 4. Senonches, France.

In the best types of hydraulic limestones, silica varies between 13 and 17 per cent, while alumina and iron oxide together rarely exceed 3 per cent.

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[1] Min. Res., U. S. Geol. Surv., 1907: 491, 1908.

Natural Rock Cements (2, 43). — These, known also as Roman cement, quick-setting cement, and Rosendale cement, are made by burning a silico-aluminous limestone (containing from 15 to 40 per cent clayey impurities) at a temperature between decarbonation and clinkering. The product shows little or no free lime. The following analyses will give some idea of the range in composition of natural cement rocks quarried in the United States: —

ANALYSES OF NATURAL CEMENT ROCKS

	UTICA, ILL.	LOUISVILLE DISTRICT	FORT SCOTT, KAN.	HANCOCK, MD.	HANCOCK, MD.	MANKATO, MINN.
SiO_2	17.01	15.21	17.26	19.81	24.74	10.10
Al_2O_3	3.35	4.07	2.05	7.35	16.74	2.78
Fe_2O_3	2.39	1.44	5.45	2.41	6.30	1.34
CaO	32.85	33.99	34.45	35.76	23.41	25.96
MgO	8.45	7.57	5.28	2.18	4.09	14.91
Alk.	n.d.	—	—	n.d.	6.18	3.50
SO_3	1.81	—	—	n.d.	2.22	.26
CO_2	34.12	35.03	32.87	31.74	22.90	41.29
H_2O					—	—

	LAWRENCEVILLE, N.Y.	LAWRENCEVILLE, N.Y.	HOWES CAVE, N.Y.	JAMESVILLE, N.Y.	AKRON-BUFFALO DISTRICT	MILWAUKEE, WIS.
SiO_2	10.90	23.80	12.89	10.97	9.03	17.56
Al_2O_3	3.40	4.17	11.15	4.46	2.25	1.40
Fe_2O_3	2.28	4.71		1.54	.85	2.24
CaO	29.57	22.27	30.90	27.51	26.84	27.14
MgO	14.04	12.09	9.38	16.90	18.37	13.89
Alk.	n.d.	n.d.	—	—	.85	—
SO_3	.61	.90	—	—	n.d.	—
CO_2	37.90	31.00	34.60	37.94	40.33	36.45
H_2O	n.d.	n.d.	—	—	.98	—

Natural cements differ from lime in possessing hydraulic properties, and refusal to slake unless ground very fine. They differ from Portland cements in lighter weight, lower temperature of burning, quicker set, lower ultimate strength, and greater latitude of composition. Magnesia is not regarded as a detrimental impurity in natural cements as it is in Portland cement.

The following are some analyses of the burned material: —

ANALYSES OF SOME NATURAL ROCK CEMENTS

	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O, K_2O	IGNITION
Natural rock cement, Rosendale, N. Y.	34.38	18	30.5	6.84	2.42	3.98	3.78
Natural rock cement, Akron, N. Y. . .	40.68	22	22.62	7.44	1.40	2.23	3.63
Natural rock cement, Cumberland, Md.	43.97	2.21	22.38	11.71	2.29	9.00	2.44
Roman cement, Rüdersdorf, Germany	56.45	4.84	27.88	6.19	4.64	—	—

Portland Cement (2). — Portland cement is the product obtained by burning a finely ground artificial mixture consisting essentially of lime, silica, alumina, and some iron oxide, these substances being present in certain definite proportions. Portland cement was first made by Joseph Apsdin, of Leeds, England, who desired to make an artificial cement that would replace natural hydraulic cements. It received its name because it hardened under water to a mass resembling the Portland stone of England.

The following combinations of raw materials are at present used in the manufacture of true Portland cement in the United States: *marl and clay*; *limestone and clay, or shale*; *chalk and clay*; *pure limestone and argillaceous limestone.*

In these combinations it is evident that the substances first named supply most of the lime and the second most of the silica, alumina, and iron. In the fourth the argillaceous limestone supplies some lime, as well as the silica and alumina. The nature of the raw materials chosen depends to a large degree on the location of the plant, whether in a limestone- or a marl-producing region. Where both of these raw materials are available, as in parts of New York, questions of manipulation in the process of manufacture govern the selection of one or the other.

Marls, for example, though easier to excavate and reduce than limestones, contain so much more organic matter and water than limestones that they are more expensive to handle and prepare. Marl beds are likewise apt to be of limited extent and irregular, while limestone beds are, so far as the needs of a manufacturing plant are concerned, practically limitless.

Comparing clay and shale,[1] the former is often easier to excavate, but, on account of the water it contains, has to be dried before it can be ground and mixed. The fossils in shales are sometimes an important source of calcium carbonate, and then careful grinding and mixing is necessary to bring about a uniform distribution of the lime through the mass. Shale is, however, used by only a few works.

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[1] It is probable that the refuse of many slate quarries could also be used in place of shale.

Argillaceous limestone, mixed with a much smaller quantity of purer limestone, as in Pennsylvania and New Jersey, is superior to a limestone and clay mixture, because less thorough mixing and fine grinding are required. In such cements, even when grinding and mixing are incompletely done, the particles of argillaceous limestone so closely resemble the proper mixture in chemical composition as to affect the result but little.

The following table gives the analyses of some of the raw materials used in manufacture of Portland cement: —

ANALYSES OF RAW MATERIALS USED FOR PORTLAND CEMENT

LOCALITY	MATERIAL	SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$MgCO_3$	H_2O + ORG. MATTER	MISCEL.
Lehigh Valley, Penn.	Calc. shale or cement rock	15.40	4.26	1.38	74.66	2.66	1.88	$CaSO_4$ .86
	Limestone	5.87	1.59		88.00	4.00		
	mixture	13.97	5.07	1.88	74.1	2.04	1.82	
Glens Falls, N. Y.	Limestone	3.3	1.3		CaO 52.15	MgO 1.58		SO_3 .3
	Clay	55.27	28.15		CaO 5.84	MgO 2.25	8.37	SO_3 .12
Warners, N. Y.	Marl	.26	.10		94.39	.38	4.64	
	Clay	40.48	20.95		25.80	.99	8.50	
Sandusky, Ohio	Marl	Insol. 1.28	1.72		92.70	.50	1.13	$CaSO_4$ 2.06
	Clay	64.70	11.9	9.9	CaO .90	MgO .70	11.9	
White Cliffs, Ark.	Chalk	7.97	1.09		88.64	.73		
	Clay	53.3	23.29	9.52	CaO .36	MgO 1.49	5.16	

In the selection of the raw materials the aim of the manufacturers is to produce a raw mixture which runs approximately 75 per cent carbonate and the balance clay. In the burning of this mixture, which must be done at a high temperature (often estimated at 3000° F.), a fused mass termed clinker is formed. This consists probably of silicates, aluminates, and ferrites of lime. The finely ground clinker, which is the Portland cement, is blue to gray in color, and has a specific gravity of 3 to 3.25.

In some localities argillaceous limestones are found which approach so closely to the proper composition, that but little additional material has to be added to make a mixture of the proper composition.

The raw materials must not only have the proper composition, but they also must show proper physical character, extent, and location, with respect to market and fuel supplies. As regards composition, 5 or 6 per cent magnesium carbonate is about the permissible limit. Chert, flint, or sand are also undesirable impurities, and alkalies and sulphates should not exceed 3 per cent. For a clayey limestone the limiting values for silica, alumina, and iron are:

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} > 2 \text{ and } \frac{SiO_2}{Al_2O_3 + Fe_2O_3} < 3.5.$$

The following are analyses of Portland cement mixtures before burning:[1] —

ANALYSES OF PORTLAND CEMENT MIXTURES

SiO_2	12.85	12.92	13.52	14.94
Al_2O_3	4.92	4.83	6.56	2.66
Fe_2O_3	1.21	1.77	—	1.10
$CaCO_3$	76.36	75.53	75.13	75.59
$MgCO_3$	2.13	4.34	4.32	4.64
	97.47	99.39	99.53	98.93

The following analyses will serve to illustrate the composition of some American Portland cements: —

ANALYSES OF CEMENTS

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
Empire brand	22.04	6.45	3.41	60.92	3.53	2.73
Sandusky	23.08	6.16	2.90	62.38	1.21	1.66
Alpha	22.62	8.76	2.66	61.46	2.92	1.53

Distribution of Lime and Cement Materials in the United States. *Limestone for Lime.* — Limestones of suitable composition for making lime are so widely distributed that no particular regions or states require special mention.[2] In the New England states, crystalline limestones are the chief source of supply. In the Appalachian states, from New York to Alabama, there are many Paleozoic limestones of high purity, notably the Trenton, Lower Helderberg, and Carboniferous limestones (see state references). The same series of rocks are also of importance in the Mississippi Valley states from Tennessee (52) to Michigan (35). Lime of excellent quality is obtained from the Subcarboniferous in Iowa (23, 24), Kansas (25), and Missouri (53), and from the Cretaceous in Texas (53). Limestones suitable for lime manufacture are also found in numerous localities in the Pacific coast states (53).

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[1] U. S. Geol. Surv., Min. Res., 1907.

[2] Analyses and detailed descriptions will be found in the areal reports, mentioned in the list of References.

Hydraulic Limes (2). — Largely because of the great abundance of natural-rock cements, which are of superior value, these materials, though much used abroad, are of no importance in the United States.

It is stated that in 1906 and 1907[1] several natural cement plants have been making and marketing a true hydraulic lime, but no output is given for 1908.

Natural Rock Cements (2, 43, 53). — Calcareous rocks for making natural cement are found at a number of points, the more important ones being given in summarized form in the following table: —

GEOLOGIC AGE OF NATURAL CEMENT ROCKS IN THE UNITED STATES

STATE	GEOLOGIC AGE	STATE	GEOLOGIC AGE
Georgia	Cambro-Ordivician	Ohio	Devonian
Illinois	Ordovician	Pennsylvania	Ordovician
Indiana-Kentucky	Devonian	Texas	Cretaceous
Kansas	Carboniferous	Virginia	Cambrian
Maryland	Silurian	West Virginia-Maryland	Cambrian
Minnesota	Ordovician	Wisconsin	Devonian
New York	Silurian		
North Dakota	Cretaceous		

In many districts the cement rocks occurs in more than one bed, and may be interstratified with limestones or shales of no economic value for cement making (Fig. 54).

Some of the important occurrences may be briefly referred to.

New York (43). — This state contains four localities in which natural cement rock is found, these in the order of their importance being: 1. Rosendale District in Ulster County; 2. Akron-Buffalo District in Erie County; 3. Fayetteville-Manlius District in Onondaga County (mostly); 4. Howe's Cave, Schoharie County. The following chart shows their occurrence at different horizons in the Silurian: —

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[1] U. S. Geol. Surv., Min. Res., 1907 : 490, 1908.

PLATE XVIII

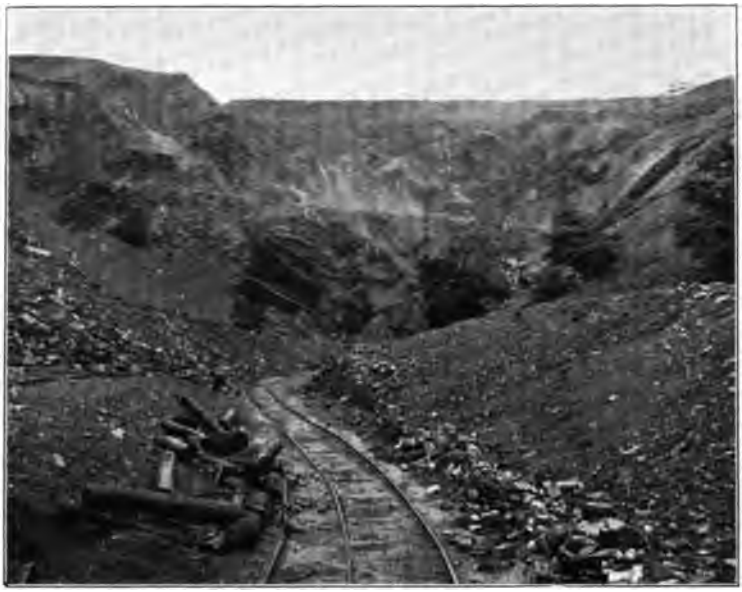

FIG. 1. — Quarry of natural cement rock, Cumberland, Md. (*H. Ries, photo.*)

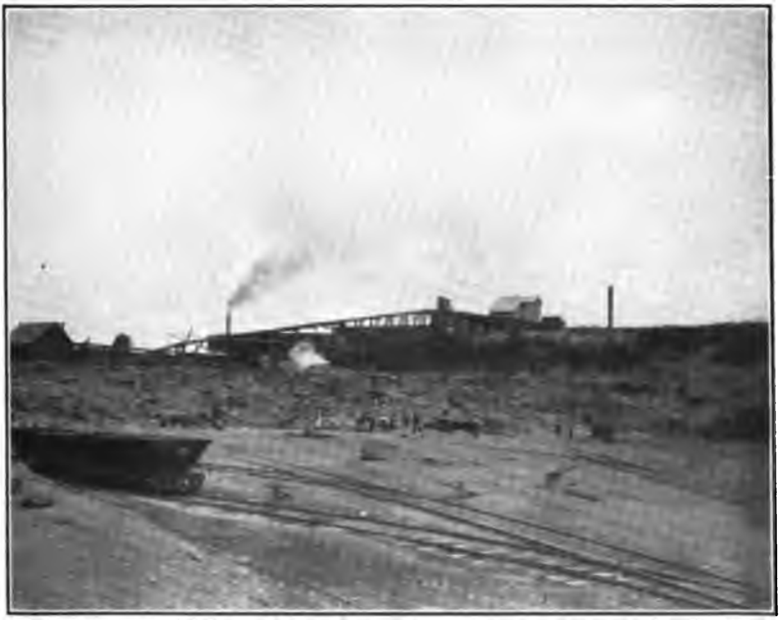

FIG. 2. — Natural cement rock quarry, Milwaukee, Wis. (*H. Ries, photo.*)

FORMATION	ULSTER CO.	SCHOHARIE	ONONDAGA	ERIE
Manlius	Present, not worked for cement	Worked at Howe's cave	Worked for cement at Manlius, etc	Absent
Rondout	Upper cement bed of Rondout district	Worked for cement at Howe's Cave	Present, but not worked	Absent
Cobleskill	Present	Not used for cement		
Bertie	Lower cement bed of Rondout district	Absent	Present in Onondaga Co., but rarely used	Worked around Akron and Buffalo
Wilber	Limestones	No cement		

In Rosendale district (Figs. 52 and 53), two distinct beds are worked usually, which differ in chemical composition and geologic age. The lower or dark bed, according to Darton, averages about 21 feet, while the upper or light bed is about 11 feet, the two being separated by 14–15 feet of worthless limestone.

The lower bed rests directly on Clinton quartzite.

The folding and faulting are intense in the Rosendale district (Fig. 53), but the beds show little disturbance in the others.

Other States. — Southward from New York natural cement rock is quarried at a number of points along the Appalachians, but owing to the folded character of the beds the extraction is often difficult (Pl. XVIII, Fig. 1). The Lehigh district of Pennsylvania is an important producer of natural cement, but still more so of Portland cement (p. 149).

Several beds are worked in the Cumberland-Hancock area of Maryland (32, 33), while in Virginia (55) limestones of suitable composition for natural cement manufacture occur at several horizons, but only the argillaceous magnesian limestones found in the lower part of the Shenandoah (Cambro-Ordovician) limestone will probably prove of economic value. Others are worked in Georgia (14, 15, 53.)

Natural cement has been made at Utica, Ill. (53), from dolomitic limestone (Fig. 54), for nearly fifty years.

Near Milwaukee, Wisconsin (53), the cement beds occur interstratified with Devonian limestone (Pl. XVIII, Fig. 2). Farther west near Fort

Scott, Kansas (25), slightly magnesian Carboniferous argillaceous limestones are worked.

Cement rock is also obtained in southeastern Ohio (44), and at Louisville, Kentucky (29), probably the second most important center in the United States.

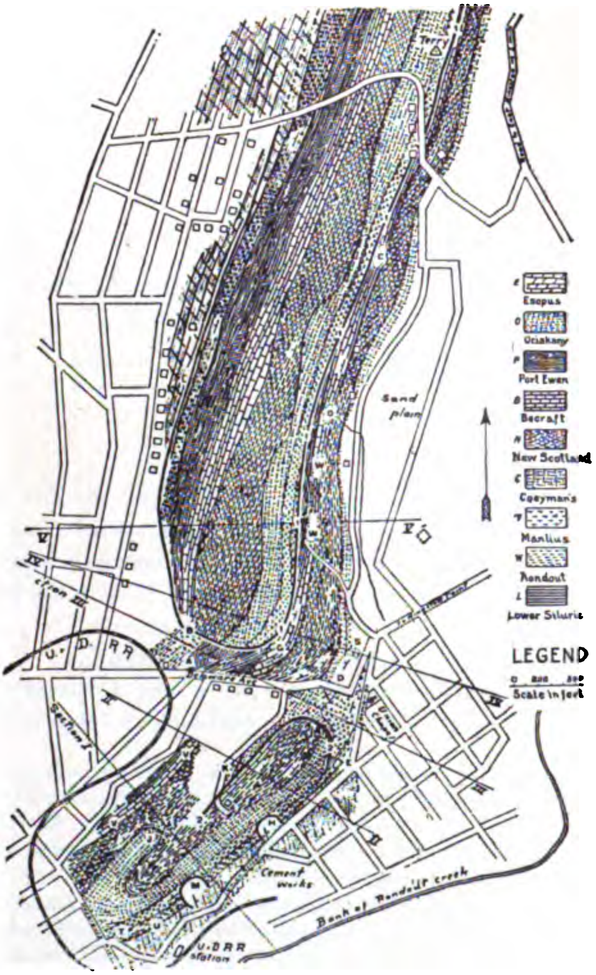

FIG. 52. — Geologic map through the Vlightberg at Rondout, N. Y. (*After van Ingen, N. Y. State Mus., Bull.* 69.)

Portland Cements. — Clay and limestone, in one form or another, are so widely distributed throughout the United States that it is possible to manufacture Portland cement at many localities,

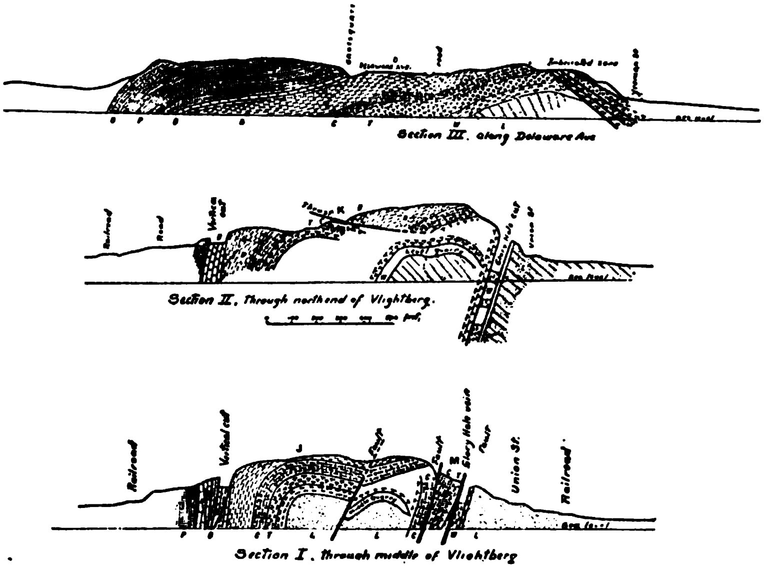
Section III. along Delaware Ave
Section II. Through north end of Vlightberg.
Railroad
Road
Vertical cut
Section I. through middle of Vlightberg
Railroad
Vertical cut
Union St.
Railroad

Fig. 53. — Geologic sections through the Vlightberg, showing position of natural rock cement beds. (*After van Ingen, N. Y. State Mus., Bull.* 69.)

and the geologic age of the materials used ranges from Ordovician to Pleistocene (53), (Refs. under different states). Twenty-five states were making this cement in 1908, the factories being spread over the country from the Atlantic to the Pacific (Fig. 58).

Pennsylvania.—By far the most important district is the Lehigh Valley in Pennsylvania, which supplies about 39 per cent of the domestic product.

The cement belt lies in Northampton and Lehigh counties, Pennsylvania (Fig. 55), and the geologic section involved is as follows (50): —

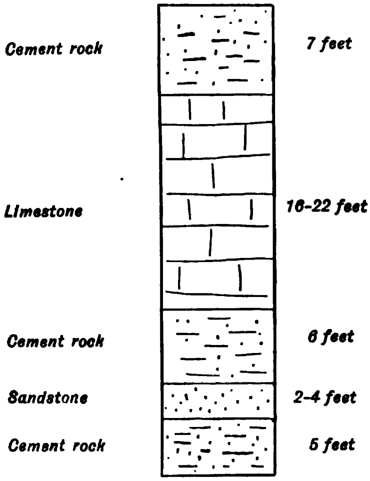

Fig. 54. — Section in cement quarries at Utica, Ill. (*After Eckel.*)

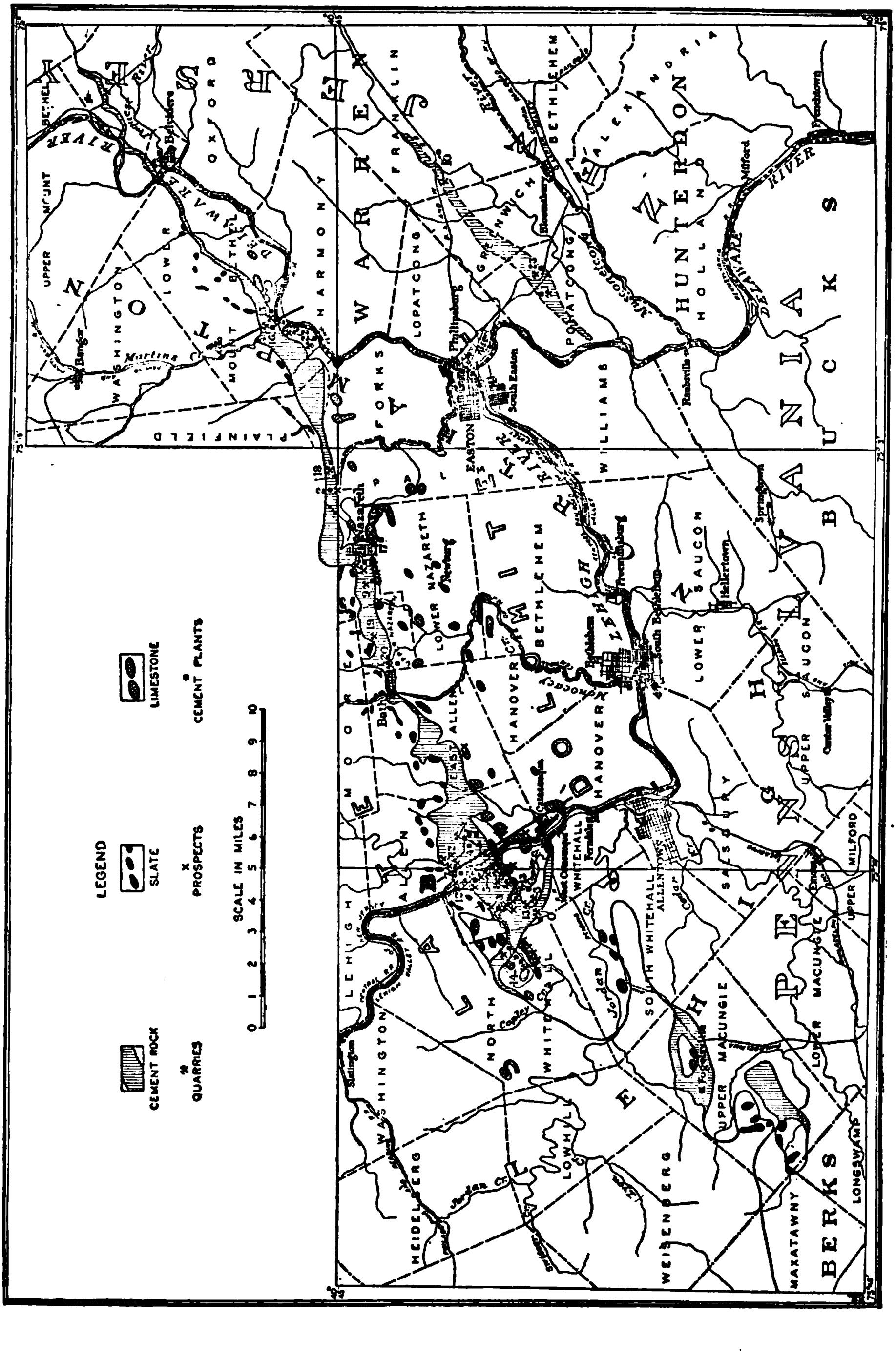

FIG. 55. — Map of cement belt of eastern Pennsylvania. (*After Peck, Econ. Geol., III.*)

Hudson River slate.	Probably 500 feet thick. No limestone. Sharp boundary.
Trenton limestones.	More or less argillaceous slaty limestone, the cement rock. Nearly pure limestones with some dolomitic beds.
Cambrian	Kittatinny dolomites and dolomitic limestones. 3000′±. Some beds flinty, and lowest are siliceous. Basal conglomerates or quartzite.
Pre-Cambrian rocks.	Mainly gneisses.

The lower member of the Trenton varies in its physical character, and furnishes material to raise the lime content of the cement rock for Portland cement manufacture. Its lime carbonate content varies from 80 to 97 per cent, but occasionally drops to 70 per cent, while the magnesian carbonate runs from 1.5 to 3 per cent. In a few it reaches 20 per cent, and these highly magnesian layers cause trouble in quarrying. The upper or slaty member of the Trenton grades into the lower one. The rocks of this region have, by post-Carboniferous folding, been bent into a complex series of folds (Figs. 56 and 57), whose axes trend northeast and southwest, and while the folds are in many cases overturned, there is comparatively little faulting.

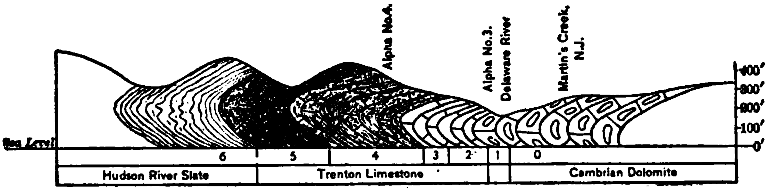

FIG. 56. — Diagramatic section two miles long extending northwest from Martin's Creek, N. J., showing overturned folds. 0 and 1 = Cambrian dolomite; 2 and 3 = Lower Trenton, rocks high in lime; 4 = cement rock, Upper Trenton, averaging 70 to 80 per cent $CaCO_3$; 5 = Upper Trenton cement rock with less than 70 per cent $CaCO_3$; 6 = Hudson River slate. (*After Peck, Econ. Geol.*, III.)

The cement rock extends as a continuous zone or belt of varying width southwest across Northampton County from the Delaware to the Lehigh River (Fig. 55), crosses into Lehigh County, and ends abruptly at a point four and a half miles west of Coplay.

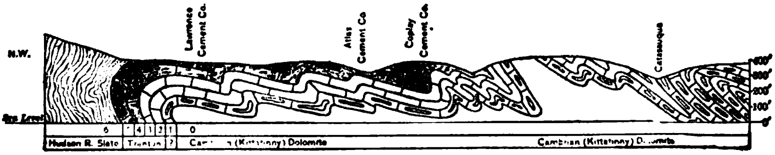

FIG. 57. — Diagramatic section five miles long extending northwest from Catasauqua. Numbers same as in Fig. 56. (*After Peck, Econ. Geol.*, III.)

The same beds are found in the adjacent territory of New Jersey (38).

Other States. — In the eastern half of New York (43) the Ordovician and Silurian limestones form an inexhaustible supply of material to mix with Pleistocene surface clays. In the south central part of New York the Tully limestone and Hamilton shales are employed, while in the central and southwestern portion beds of marl (Pl. XIX, Fig. 2), associated with surface clays, are utilized.

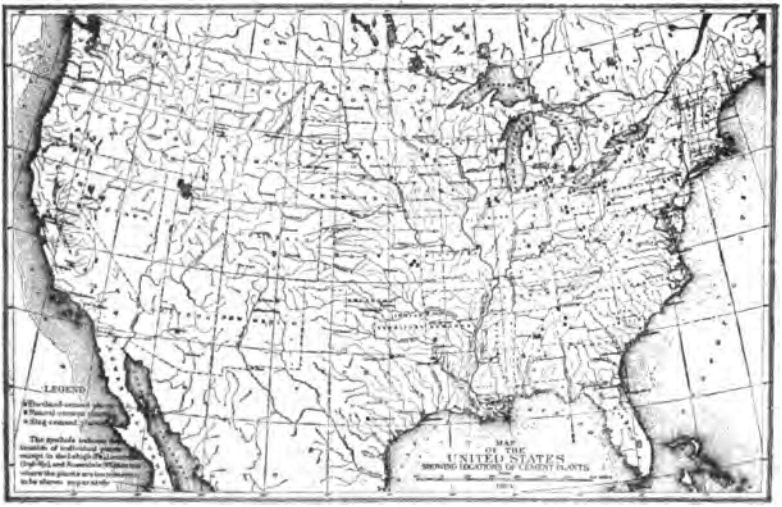

Fig. 58. — Map of United States, showing location of cement plants. (*After Eckel, U. S. Geol. Surv., Bull.* 243.)

Ohio (46, 47), Indiana (18–21), and Michigan (34–36) are important Portland cement producing states. The abundance of marl and Pleistocene clays makes them the favorite materials, notwithstanding the fact that beds of Paleozoic limestones occur in each of the states. Marl, although especially abundant in Michigan, is found in many states lying east of the Mississippi and north of the terminal moraine. It is precipitated from the waters of ponds through the agency of minute plants, especially *Chara* (35).

In Kansas Carboniferous shales and limestones are used for making Portland cement (25, 26, 28), and in Texas and Arkansas the Cretaceous shales and chalky limestones are employed (13, 14, 53); Alabama has a Cretaceous limestone of such composition that very little clay or shale has to be added to it (12). Portland cement is also manufactured in North Dakota (53), South Dakota (51),

PLATE XIX

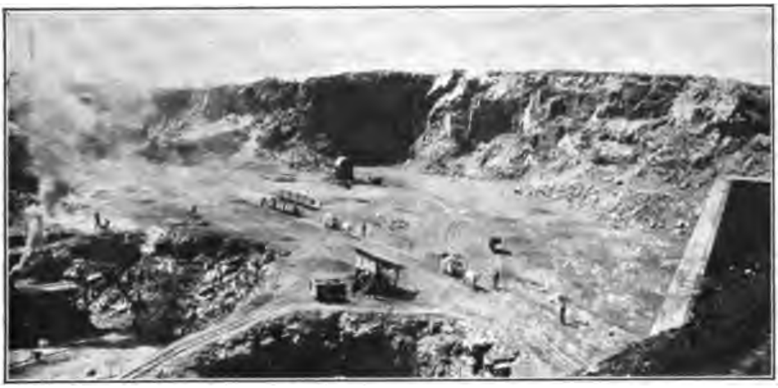

FIG. 1. — Limestone quarry in Lehigh cement district, Pennsylvania. (*H. Ries, photo.*)

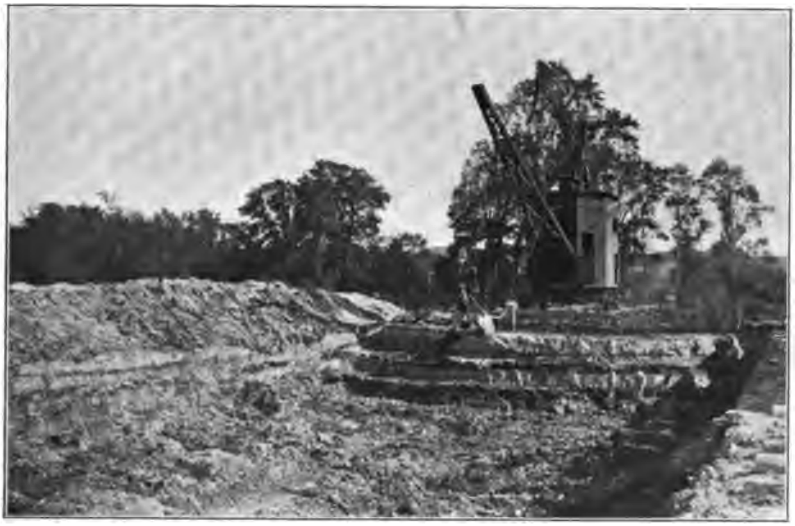

FIG. 2. — Marl pit at Warners, N. Y. The dark streaks are peat, and the marl is underlain by clay. (*H. Ries, photo.*)

Utah (53), Colorado (53), and California (15, 53).

Uses of Lime (43, 2). — The most important single use of lime is for mixing with sand to form mortar, and many thousands of tons are used annually for this purpose. In addition to this use lime is employed for a great variety of purposes, of which the following are the most important: as a purifier in basic steel manufacture; in the manufacture of refractory bricks, ammonium sulphate, soap, bone ash, gas, potassium dichromate, paper, pottery glazes, and calcium carbide; as a disinfectant; as a fertilizer; as a polishing material; for dehydrating alcohol, preserving eggs, and in tanning.

Uses of Cement (2, 5). — The use of hydraulic cement is constantly increasing in the United

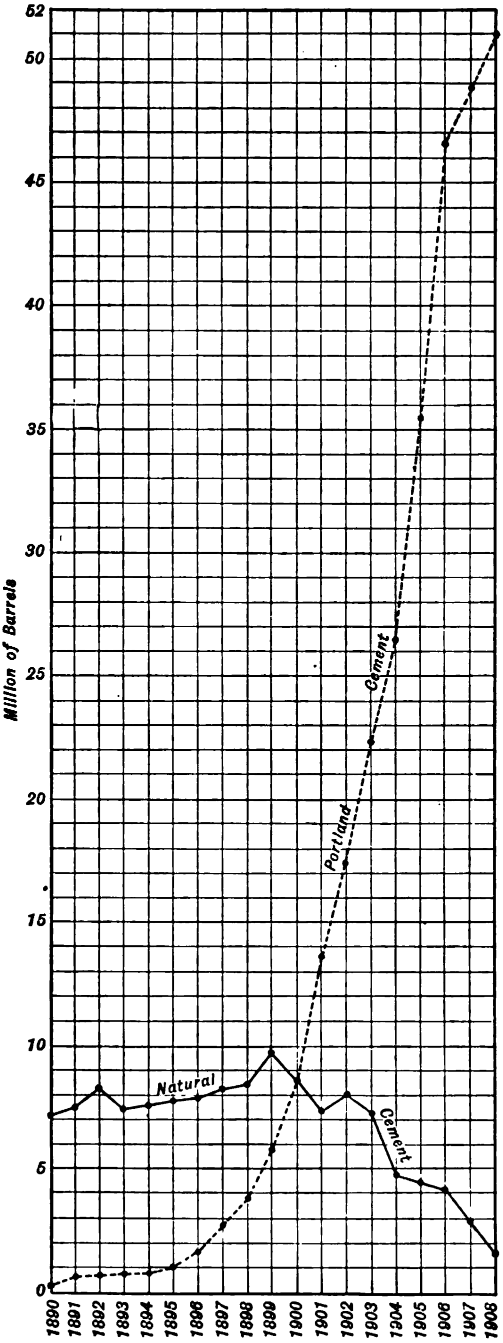

FIG. 59. — Chart showing production of Portland and natural cements, 1890 to 1908. (*After Eckel, U. S. Geol. Surv., Min. Res.*, 1908.)

States, this being specially true of Portland cement, which is superseding natural cement to a great extent, and is finding an increasing use in building and engineering operations. For pavements, Portland cement is probably more extensively used in America than in any other country; and as an ingredient of concrete it is widely employed. Blocks weighing as much as 65 to 70 tons have been made for harbor improvements at New York City (5).

Production of Cement. — The following tables give the production of natural-rock and Portland cement. Those given for the latter cover a greater period than those of the former, and are grouped with figures of import and consumption in order to show more clearly the tremendous growth of the American Portland cement industry.

The diagram (Fig. 59) shows most clearly the remarkable increase in the production of Portland cement, and the rapid decrease in the natural cement production, the latter being now of small importance in the cement industry.

PRODUCTION OF PORTLAND CEMENT BY STATES, IN 1908

STATE	PRODUCING PLANTS	QUANTITY (barrels)	VALUE	STATE	PRODUCING PLANTS	QUANTITY (barrels)	VALUE
Pennsylvania	17	18,254,806	$13,899,807	Texas . . .	2	917,977	$ 924,039
Indiana . .	7	6,478,165	5,386,563	Oklahoma .	2		
Kansas . .	7	3,854,603	2,874,457	South Dakota	1	809,306	1,057,433
Illinois . . .	5	3,211,168	2,707,044	Colorado . .	2		
New Jersey .	3	3,208,446	2,416,009	Arizona . .	1	507,603	805,235
Michigan . .	15	2,892,576	2,556,215	Utah . . .	2		
Missouri . .	4	2,929,504	2,571,236	Maryland . .	1	502,225	511,118
California . .	4	2,480,100	3,268,196	Virginia . .	1		
Washington .	2			Massachusetts	1		
New York .	7	1,988,874	1,813,623	Alabama .. .	2	310,244	274,995
Ohio . . .	8	1,521,764	1,305,210	Georgia . .	1		
Iowa . . .	1	1,205,251	1,176,499				
Kentucky .	1						
Tennessee .	1						
					98	51,072,612	43,547,679

This is perhaps hardly a fair year to take, as nearly all mineral industries showed a falling off, owing to the business depression of 1907–1908. Portland cement, however, showed a slight increase in the quantity of production.

PRODUCTION OF POZZUOLAN CEMENT IN THE UNITED STATES, 1904–1908

YEAR	QUANTITY (barrels)	VALUE	YEAR	QUANTITY (barrels)	VALUE
1904	303,045	$226,651	1907	557,252	$443,998
1905	382,447	272,614	1908	151,451	95,468
1906	481,224	412,921			

PRODUCTION OF NATURAL CEMENT IN THE UNITED STATES

	1904		1905		1906		1907		1908	
	QUANTITY (barrels)	VALUE	QUANTITY (barrels)	VALUE	QUANTITY (barrels)	VALUE	QUANTITY (barrels)	VALUE	QUANTITY (barrels)	VALUE
New York	1,911,402	$1,138,667	1,926,837	$1,332,809	1,515,866	$1,055,785	947,929	$633,170	623,618	$441,136
Pennsylvania	770,897	298,533	748,057	306,552	744,403	560,534	645,871	263,969	252,479	87,192
Indiana	735,000	367,953	527,600	211,040	600,000	240,000	400,000	140,000	212,901	42,580
Illinois	360,308	113,000	368,645	116,549	365,843	118,221	284,599	92,750	188,859	68,772
Kansas	210,922	79,456	230,686	110,750	238,311	129,781	129,077	71,052	87,159	47,725
Texas	[1]	[1]	[1]	[1]						
Colorado										
Kentucky	264,104	132,052	207,500	83,000	Under O.		338,195	176,379		
Georgia	66,500	37,750	89,167	51,040	180,500	98,075			119,656	53,904
Ohio	[1]	[1]	64,791	51,235	170,194	95,539				
Minnesota	138,000	65,620	115,314	57,643	177,330	92,560	162,029	89,982	202,190	93,200
Wisconsin	250,000	150,000	139,128	63,737						
Maryland	65,000	32,500	55,324	28,694	63,350	32,675	Included with Ga., Ky., and O.			
Virginia	93,292	59,619	[1]	[1]	Under O.					
North Dakota	[1]	[1]			Under Minn., Wis.		With Minn. and Wis.			
West Virginia	[1]	[1]	[1]	[1]						
Total	4,866,331	$2,450,150	4,473,049	$2,413,052	4,055,797	$2,423,170	2,887,700	$1,467,302	1,686,862	$834,509

[1] Included with some of the other states.

PRODUCTION OF PORTLAND CEMENT IN THE UNITED STATES, 1904–1908

	1904		1905		1906		1907		1908	
	QUANTITY (barrels)	VALUE	QUANTITY (barrels)	VALUE	QUANTITY (barrels)	VALUE	QUANTITY (barrels)	VALUE	QUANTITY (barrels)	VALUE
United States production	26,505,881	$23,355,119	35,246,812	$33,245,867	46,463,424	$52,466,186	48,785,390	$53,992,551	51,072,612	$43,547,679
Imports[1]	968,410		896,845		2,273,493		2,033,438		842,121	
Total	27,474,291		36,143,657		48,736,917		50,818,828		51,915,033	
Exports[1] (domestic and foreign)	774,940	1,104,086	897,686	1,387,906	583,299	944,886	900,550	1,450,841	846,528	1,249,229
Apparent consumption	26,699,351		35,245,971		48,153,618		49,918,278		51,068,505	

[1] Portland cement forms probably 90 to 95 per cent of the imports.

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CHAPTER VI

SALINES AND ASSOCIATED SUBSTANCES

UNDER this heading are included Salt, Borax, Sodium Sulphate, Sodium Carbonate, and Sodium Nitrate. Bromine and calcium chloride, being regardable as by-products from salt brines, are referred to under Salt. Iodine is described under Sodium Nitrate.

SALT

Types of Occurrence. — Common salt, the chloride of sodium (NaCl), is a widely distributed mineral, being found: (1) in solution in sea water or salt lakes; (2) as solid masses termed rock salt; (3) as natural brine in cavities or pores of the rocks, from which it may exude as salt springs or be tapped by wells; and (4) in marshes and soils.

Although all four of these types of occurrence may serve as commercial sources of salt, it is only the second that is of great economic importance.

Occurrences of Salt in Sea and Lake Waters.—Salt is present in all ocean water, and also in that of most inland lakes or seas having no outlet. As can be seen from the following analyses, the percentage of salt is greater in some salt lakes than in the ocean: —

LOCALITY	SALTS IN SOLUTION	WATER	PERCENTAGE OF SALTS IN SOLID MATTER						
			$NaCl$	KCl	$MgCl_2$	$NaBr$ $MgBr_2$	$CaSO_4$	$MgSO_4$	$CaCO_3$ $MgCO_3$
Black Sea . . .	1.77	98.23	79.39	1.07	7.38	.03	.60	8.32	3.21
Mediterranean Sea.	3.37	96.63	77.03	2.48	8.76	.49	2.76	8.34	.10
Atlantic Ocean . .	3.63	96.37	77.07	3.89	7.86	1.30	4.63	5.29	—
Dead Sea	22.30	77.70	36.55	4.57	45.20	.85	.45	—	$CaCl_2$ 11.38
Great Salt Lake .	14.99	85.01	79.12	.57	9.93	—	.56	6.21	K_2SO_4 3.47

Salt is sometimes obtained by artificial evaporation from both the ocean and salt lakes; but in the United States this plan is profitable only under exceptional conditions, as around San Francisco Bay, California (8), or Great Salt Lake, Utah.

Rock Salt. — Rock salt, which is the most important source of commercial salt, occurs commonly in layers of variable thickness and purity embedded with sedimentary rocks, such as shales or sandstones. It is frequently associated with gypsum, and less commonly with limestone, or easily soluble compounds of magnesia, potash, and lime. Less often, the rock salt is found in domelike masses in stratified rocks, but not conformable with them. Rock salt deposits vary in thickness from a few inches up to as much as 3600 feet (Sperenberg, Germany); and while found in all geological formations from the Cambrian to the Pleistocene, except the Cretaceous, the rock salt of the United States is not found in formations older than the Upper Silurian.

Origin of Rock Salt (1, 5). —One of the interesting problems of geology has been to find a correct theory to account for the origin of salt deposits. Such a problem is not as simple as it may appear at first sight, for it must explain (1) the formation of salt deposits of extraordinary thickness, (2) the association of gypsum, either above or below the salt, and (3) the presence of other minerals, which may or may not be saline ones.

Evaporation Theory. — It is generally believed that most rock salt, or rock salt and gypsum, deposits have been formed by the evaporation of oceans and lakes, this process having gone on during a number of periods from the Silurian to the present.

Now in the evaporation of a body of sea water having a composition similar to that of the present ocean, the order of precipitation would be (1) iron hydroxide, (2) lime carbonate, (3) calcium sulphate, (4) sodium chloride, (5) easily soluble compounds, such as sulphates and chlorides of potash and magnesia, etc., these being often of quite complex composition.

In such a series, of course, the periods of deposition are not sharply separated, but overlap somewhat as shown by Usiglio.

Simple as the phenomena of concentration of sea water appear, they yet may be complex, and it is possible as well as probable that the order of precipitation is not always according to order of solubility, this being governed to some extent at least by other salts present, degree of concentration, and temperature.

There are few places where a complete section can be found, and the most nearly perfect one is that at Stassfurt in Prussia, where more than thirty saline minerals are known to occur.

The section there, beginning at the top, is given below, and it will be seen there that in the upper part of the section (especially Nos. 2–5), the order of precipitation is not exactly according to the order of solubility of the different salts.

1. Permian (?) sandstones and shales.
2. Gypsum and anhydrite of variable thickness.
3. Younger rock salt, thickness variable. Sometimes absent.
4. Anhydrite.[1] From 30 to 80 meters thick. Rarely absent.
5. Salt clay. Averages 5 to 10 meters. Occasionally absent.
6. Potash salts (Carnallite, KCl, $MgCl_2$, 6 H_2O), 15 to 40 meters thick. Always mixed with kieserite and rock salt.
7. Kieserite ($MgSO_4$, H_2O) zone. Same thickness as preceding, and containing layers of rock salt.
8. Polyhalite zone (K_2SO_4, $MgSO_4$, 2 $CaSO_2$, 2 H_2O). About 60 meters thick, and consisting of alternating layers of rock salt and polyhalite.
9. Older rock salt and anhydrite. The anhydrite forms layers in the salt averaging 7 centimeters in thickness, and thought by some to represent annual deposits, caused by seasonal temperature variations, or alternating dry and rainy periods.
10. Anhydrite and gypsum.

Where layers of clay or shale occur between the beds of salt or gypsum, they may represent sediment washed in during the period of precipitation, the influx of fresh water carrying this sediment being sufficient to dilute the brine, and temporarily arrest the deposition of the salines.

Deposits of gypsum alone may be accounted for by assuming that the concentration did not proceed far enough to precipitate the less soluble substances, or if deposited they may have been subsequently removed by solution in underground waters. The theory that the oceans of other periods had a different composition from the modern one might likewise account for beds of salt or gypsum alone. Some thin deposits of salt may have been formed by simple evaporation, and it is well known that salt is deposited in the course of evaporation of inland seas, such as the Dead Sea.

The great thickness of many salt deposits is, however, not so satisfactorily explainable; as it can be easily seen that in order to produce even a 15-foot bed of salt, would require the evaporation of an ocean of enormous depth, assuming its salinity to be anything like the present one.

Bar Theory. — This theory, which seeks to explain the origin of salt deposits of great thickness, was first suggested by G. Bischof,[2] and later elaborated by Ochsenius (1, 4). It assumes a barrier partly shutting out the ocean water. Evaporation on the inclosed area of the sea exceeds the supply of water from inflowing rivers and from the open ocean. Therefore the water on the surface of the sea becomes more dense and settles to the bottom of the basin, being prevented from escape into the open ocean by the barriers at the entrance. As the surface of the bay is lowered by evaporation, ocean waters enter, furnishing a constant supply of salt. If the barrier is complete, forming a bar, sea water may enter only at times of high tide or storm. Eventually evaporation will so concentrate the solution in the bay as to cause the precipitation of sodium chloride and other salts. So long as these conditions lasted, salt would be precipitated, but beds of clayey material would be deposited wherever fine-grained sediment was supplied from the land.

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[1] For origin of anhydrite see under Gypsum.

[2] Allgemeine Chemische u. Physikalische Geologie, II: 48, 1864.

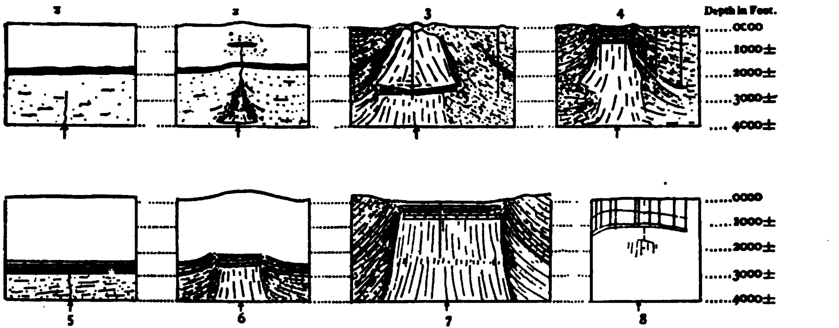

FIG. 60. — Figures representing the origin of dome structure by crystalline growth. (*After Harris, Econ. Geol., IV.*)

Dome Theory (Fig. 60). — In Louisiana and Texas as well as some other localities, there are found great domelike masses of rock salt, accompanied at times by gypsum, limestone, and even sulphur. G. D. Harris (6) believes they have been formed as follows: Heated waters coming up through underlying formations have become saturated with salt from deposits occurring in them. These waters found a pathway in fissures related to the differential uplifting of the rocks in the Mississippi embayment, and marking the position of anticlines. Cooling of the uprising solutions caused them to deposit the salt in these fissures. It is thought that the force exerted by the crystallizing salt was sufficient to lift up the overlying Tertiary and Quaternary beds, as the accumulation went on. These cores of salt have been pushed up through Cretaceous, Eocene, and even Quaternary strata.

Natural Brines. — These, sometimes found in porous layers of the rocks, may result either from sea water imprisoned in the layers of sediment or from the solution of rock salt by percolating waters.

Salt Marshes and Soils. — When away from the ocean, these owe their salinity to the infiltration of brine from neighboring saliferous formations. They sometimes represent the site of former salt lakes.

Distribution of Salt in the United States. — Salt deposits are found in a number of states, as shown on the map, Fig. 61, but nearly 75 per cent of the production in 1908 came from two states, New York and Michigan. Most of the domestic production is obtained either in the form of artificial brine obtained by forcing water through wells to the salt, which is then brought up in solution, or else as rock salt, raised through shafts from underground workings.

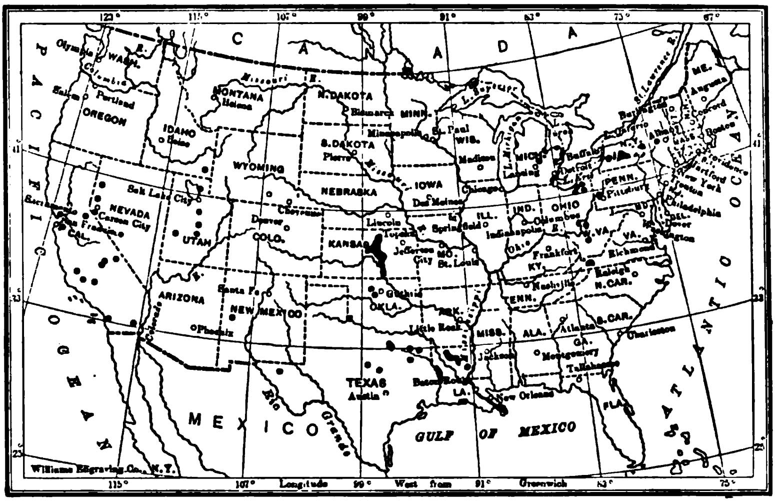

FIG. 61. — Map showing distribution of salt-producing areas in United States, compiled from various geological survey reports.

The range of geologic age of the United States deposits is shown in the following table: —

TABLE SHOWING GEOLOGIC DISTRIBUTION OF SALT IN THE UNITED STATES

STATE	AGE	STATE	AGE
California	Present	Oklahoma	Permian (?)
Kansas	Permian	Pennsylvania	Carboniferous
Louisiana	Tertiary	Texas	Cretaceous
Michigan	Silurian Mississippian	Utah	Recent
		Virginia	Mississippian
New York	Silurian	West Virginia	Middle Carboniferous (Pottsville)
Ohio	Silurian Mississippian		

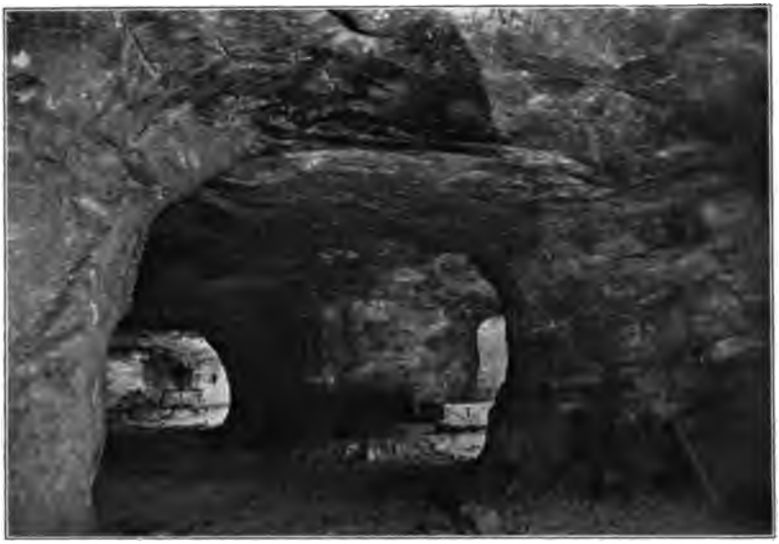

FIG. 1. — Interior view of salt mine, Livonia, N. Y. Both roof and pillar are rock salt.

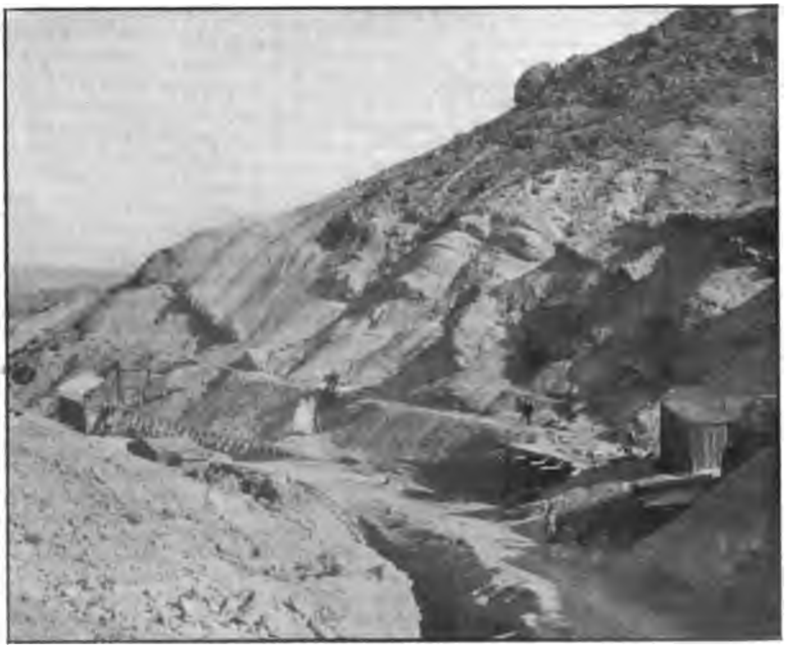

FIG. 2. — Borax mine near Daggett, Cal. (*Photo. loaned by G. P. Merrill.*)

New York (15). — Salt was manufactured from brine springs at Onondaga Lake as early as in 1788; but the presence of rock salt beds was not suspected until 1878, when a bed seventy feet thick was struck in drilling for petroleum in Wyoming County. Since then the development of the salt industry has been so rapid that for some years New York has been one of the two leading salt-producing states.

The salt occurs in lenticular masses interbedded with soft shales of the Salina series (Fig. 62), which also carry gypsum deposits. The outcrop of the formation coincides approximately with the line of the New York Central Railroad, but owing to its soluble character, no salt is found along the outcrops. The beds dip southward from 25 to 40 feet per mile, so that the depth of the salt beneath the surface increases in this direction.

At Ithaca, salt is struck at 2244 feet, and there are seven beds. The thickness of the individual beds varies, but the greatest known thickness is in a well near Tully, where 325 feet of solid salt was bored through. Recently salt has been struck by a deep boring in the oil field of southwestern New York at a depth of about 3000 feet. Though most of the New York product is obtained from artificial brines, a small quantity is mined by shafts.

Michigan (13). — Salt in Michigan is obtained both from natural brines and from brines obtained by dissolving rock salt, as in New York. The natural brines occur in the sandstones of the Mississippian, the most important locality being in the Saginaw Valley, where the brines are found in the Napoleon or Upper Marshall sandstone. They are remarkable for the large amount of bromine contained, more than half the bromine produced in the United States being obtained here. The vast beds of rock salt which occur in the Salina (Monroe) are exploited along the Detroit and St. Clair rivers and at Manistee and Ludington. The salt is dissolved by lake water pumped down and then re-evaporated, and soda ash (sodium carbonate) is made from the salt to a very great extent, by forced reaction with calcium carbonate.[1]

Ohio (16). — Natural brines are obtained from the "Big Salt Sand" (Mississippian) at Pomeroy, Meigs County, but the profit in pumping them lies in the bromine and calcium chloride which they contain. In northeastern Ohio the wells pierce a bed of rock salt in the Salina (Silurian), which is 148 feet thick and interbedded with limestones and shales. The wells are about 1900 feet deep at Cleveland and 2800 feet at Kenmore, Summit County.

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[1] Private communications from Dr. A. C. Lane.

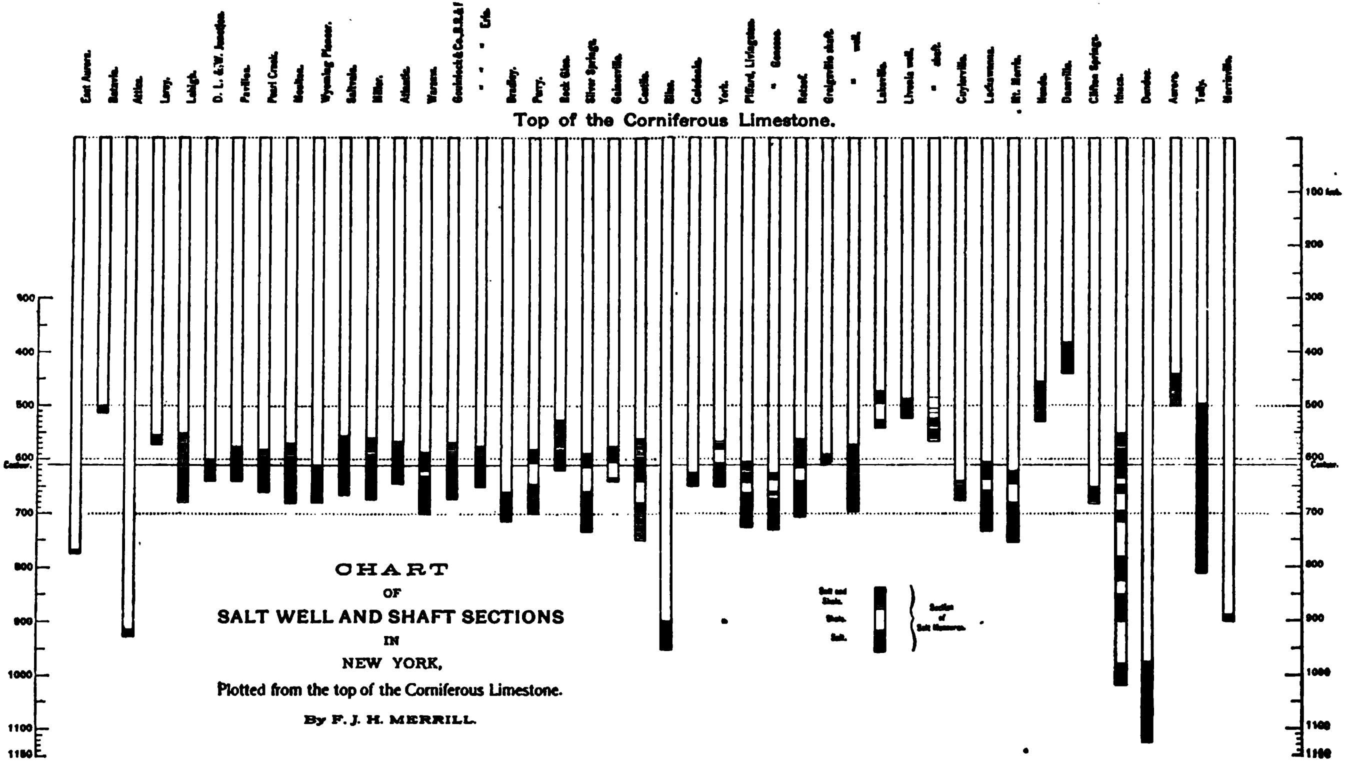

FIG. 62.—Section showing number and thickness of salt beds at different localities in New York State. (*After Merrill, N. Y. State Mus. Bull.* 11, 1893.)

The two following analyses are of interest, partly on account of their completeness. The absence of sulphate in the first is noticeable.

ANALYSES OF OHIO BRINES

	GRAMS PER LITER	
	I	II
SiO_2	.012	.000
Fe_2O_3, Al_2O_3	.083	.000
$CaCl_2$	14.340	1.033
$MgCl_2$	5.59	.462
NaCl	84.3	310.977
KCl	.114	.713
$MgBr_2$	.155	.012
$BaCl_2$	.343	.000
NaI	.004	.000
$SrCl_2$	.000	.089
$CaSO_4$	.000	4.857
LiO_2	tr.	tr.
Sp. gr.	1.075	1.204

I. Natural brine, Pomeroy, O. II. Artificial brine, Cleveland, O.

Virginia (23). — Salt, associated with gypsum, is obtained by wells from the Mississippian shaly limestones in the Holston Valley near Plasterco, Washington County (Fig. 63). Part of the product is marketed as salt, and the balance is used in the manufacture of alkali (22). The geology is referred to under Gypsum (p. 183).

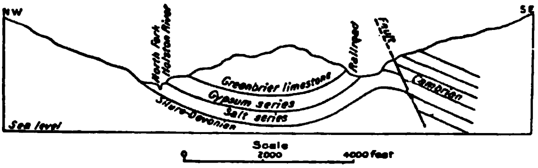

FIG. 63. — Section across Holston and Saltville valleys, midway between Saltville and Plasterco, Va. (*After Eckel, U. S. Geol. Surv., Bull.* 223.)

West Virginia (24). — Brine is obtained from the Carboniferous (Pottsville) and Mississippian (Berea) in that portion of the state adjoining the Meigs County salt district of Ohio.

Pennsylvania supplies similar brines.

Kansas (9). — Salt is found in this state under the following conditions: (1) in the northern and central parts of Kansas as brine in salt marshes derived by leaching from the saliferous Dakota shales; (2) a limited amount in eastern Kansas from wells sunk in the Carboniferous; (3) in the Permian of south central Kansas as beds of rock salt (Fig. 64). At the present time the rock salt is the most important commercial source, being obtained in part as artificial brines and in part as rock salt. The thickness of the salt varies, the greatest aggregate thickness recorded in any well being 324 feet. The deposits thin out to the eastward, and the north and south limits are fairly well known, but the western boundary remains undefined. The absence of gypsum in close association with the salt is a significant fact, but farther south it is found at a lower horizon, and the separation of the two is explained by a shifting sea bottom, during deposition.

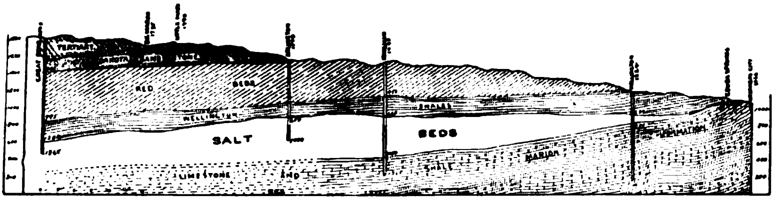

Fig. 64. — Geologic section from Arkansas City to Great Bend, Kas., showing occurrence of rock salt. (*Kas. Geol. Surv., Min. Res. Bull.*, 1898.)

Louisiana (10, 11, 12). — Brine occurs in springs and wells in the Cretaceous area of northern Louisiana, but the most important source of salt is in the extensive beds of rock salt found in the southern portion of the state. These underlie a series of low knolls, called the Five Islands (Fig. 65), and are covered by a series of clay, sand, and gravel beds. The salt occurs as great domelike masses which Harris thinks have been pushed up into Cretaceous, Tertiary, and Quaternary beds (p. 161). Salt is mined on Grande Côte or

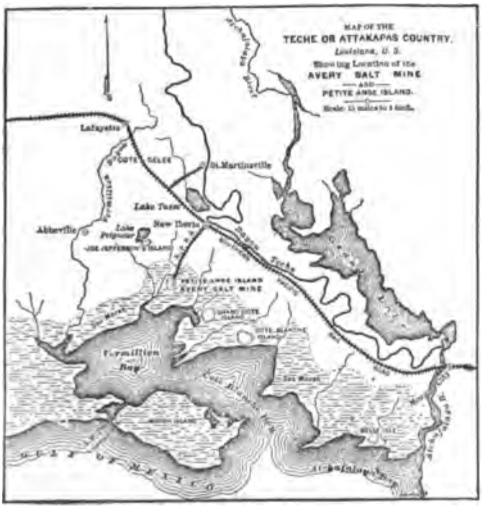

Fig. 65. — Map showing location of Petite Anse and other "salt islands," Louisiana. (*After Pomeroy.*)

Weeks Island and also on Avery Island. The age of the salt beds is pre-Pleistocene. Although the amount of rock salt present is evidently great, borings in one case revealing a thickness of 1756 feet of solid salt, these deposits yield but a small percentage of the country's output.

Other Western States. — In California the main supply of salt is obtained by evaporating sea water (8), an elaborate system of ponds, covering thousands of acres, having been built on San Francisco Bay. These are filled at high tide, and the brine evaporated by solar heat, although artificial heat is used at some of the plants. A remarkable deposit of salt has been worked at Salton Lake. This is a depression 27 miles long, 3½ to 9 miles wide, and at its lowest point 280 feet below sea level. The deposit is formed by evaporation of the lake waters, which are fed by saline springs from the surrounding foothills. The salt, which has accumulated to a depth of 6 inches, is gathered by scrapers. Salt is also found in marshes, springs, or wells in a number of other localities in California (8).

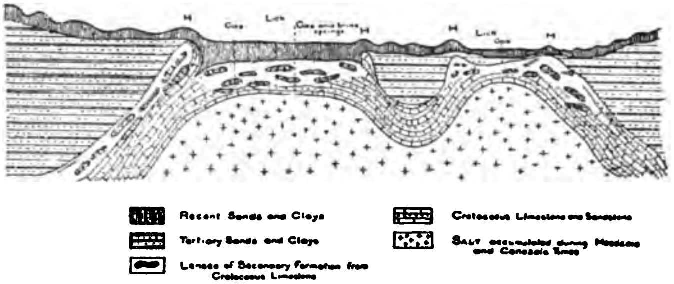
H
Gas
Lick
Gas and brine springs
H
H
Lick
Gas
H
Recent Sands and Clays
Tertiary Sands and Clays
Lenses of Secondary Formation from Cretaceous Limestone
Cretaceous Limestone and Sandstone
Salt accumulated during Mesozoic and Cenozoic Times

FIG. 66.—Section illustrating dome salt occurrence, under Cedar Lick, La. (*After Harris, La. Geol. Surv., Bull.* 7.)

In Idaho brine salt is obtained in Bear Lake and Bannock counties, near the Wyoming line; some also is produced in Churchill and Washoe counties, Nevada, Torrance County, New Mexico, and from saline lakes in several parts of Texas. Rock salt has been found at several localities in Texas, notably in Mitchell County, and under the oil beds at Beaumont, but none is yet produced.

In Utah, some salt is obtained by evaporating the waters of Great Salt Lake (21), and brines from several other localities. An enormous deposit of pure salt is reported from the west side of the Utah desert, near the Nevada state line.[1]

Throughout the Red Beds area of western Oklahama, and in parts of eastern Oklahoma, there are numerous salt springs and seepages, but Ferguson is the only locality of importance where salt is made (18).

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[1] U. S. Geol. Surv., Min. Res., 1908.

Analyses of salt. —

ANALYSES OF ROCK SALT FROM VARIOUS LOCALITIES

LOCALITY	SODIUM CHLORIDE	CALCIUM CHLORIDE	MAGNESIUM CHLORIDE	CALCIUM SULPHATE	MAGNESIUM SULPHATE	ALUMINA, SILICA, IRON	WATER	AUTHORITY
Retsof, N. Y. . . .	98.701	Tr.	—	.446	—	.743	Tr.	F. E. Englehardt
Pearl Creek, N. Y. .	96.885	.157	.103	.437	—	1.21	1.21	F. E. Englehardt
Petite Anse, La. . .	98.90	.146	.022	.838	—	.014	.08	P. Collier
Saltville, Va. . . .	99.084	Tr.	—	.446	—	.47	—	C. B. Hayden

ANALYSES OF SOLID MATTER OF BRINES FROM VARIOUS LOCALITIES

LOCALITY	SODIUM CHLORIDE	CALCIUM CHLORIDE	MAGNESIUM CHLORIDE	CALCIUM SULPHATE	MAGNESIUM SULPHATE	ALUMINA, SILICA, IRON	PERCENTAGE SOLIDS IN BRINE	SPECIFIC GRAVITY OF BRINE	AUTHORITY
Warsaw, N. Y.	97.60	.51	.20	1.68	—	—	26.34	1.204	Englehardt
Syracuse, N.Y.	95.966	.90	.69	2.54	—	.004	18.50	1.142	G. H. Cook
Saginaw, Mich.	82.14	12.39	5.01	.46	—	—	21.32	—	C. A. Goessman
Bay City, Mich.	91.95	3.19	2.48	2.39	—	—	16.61	—	C. A. Goessman
Kanawha, W. Va.	79.45	16.48	4.07	—	—	—	9.20	1.073	G. H. Cook
Pittsburg, Pa.	81.27	13.93	4.80	—	—	—	2.80	1.019	G. H. Cook
Saltville, Va.	97.792	.033	—	2.17	—	Tr.	24.60	—	C. B. Hayden
Great Salt Lake	98.10	.322	.000	.364	.021	.214	—	—	J. E. Talmadge

Extraction. — When salt forms underground deposits, it has to be extracted either by a process of solution or mining. In the former case water is forced down to the salt bed through a well, for the purpose of dissolving the salt, the brine being brought to the surface and evaporated, sometimes by solar heat, but more commonly by artificial means. In the latter case a shaft is sunk to the salt bed, and the material mined like coal and brought to the surface in lumps, known as rock salt. Natural brines are pumped to the surface for evaporation. In the evaporation of brine care has to be taken to separate the gypsum and other soluble impurities present, which precipitate before the salt does.

Uses. — Salt is largely used in the meat-packing business and the manufacture of dairy products, as well as for domestic purposes. Therefore a number of different grades are called for, known under various names, such as table, dairy, common, fine, packers, solar, rock, milling, etc. Large quantities of salt are also consumed in the manufacture of soda ash, sodium carbonate, caustic soda, and other sodium salts. The chlorination of gold ores calls for an additional large amount.

Production of Salt. — The increase in the amount of salt produced has been very marked, but it has been accompanied by a decrease in price, as shown in the statistics given below: —

Production of Salt in United States from 1880 to 1900

Year	Barrels	Value	Year	Barrels	Value
1880	5,961,060	$4,828,566	1895	13,699,649	$4,423,084
1885	7,038,653	4,825,345	1900	20,869,342	6,944,603
1890	8,876,991	4,752,286	1905	25,966,122	6,095,922

Production of Salt by States from 1904 to 1908, in Barrels

State	1904		1905		1906	
	Quantity	Value	Quantity	Value	Quantity	Value
New York . . .	8,600,656	$2,101,568	8,359,121	$2,167,931	8,978,630	$2,098,686
Michigan . . .	5,425,904	1,579,206	9,492,173	1,851,332	9,936,802	2,018,760
Ohio	2,455,829	478,523	2,526,558	565,946	3,236,785	789,237
Kansas	2,161,819	717,101	2,098,585	576,139	2,198,837	681,022
Louisiana . . .	1,095,850	320,000	1,055,186	303,507	1,179,528	268,005
California . . .	821,557	205,435	664,099	188,330	806,788	291,528
West Virginia .	575,000	66,470	202,151	74,063	200,055	57,584
Texas	376,695	149,246	444,832	142,993	360,733	170,559
Utah	253,829	321,301	177,342	135,465	262,212	169,635
Idaho	[1]	[1]	[1]	[1]	1,574	1,867
Nevada	[1]	[1]	[1]	[1]	11,249	6,420
Oklahoma . . .	[1]	[1]	[1]	[1]	9,893	4,965
Other States . .	262,863	82,372	[2] 946,075	90,216	[3] 989,294	100,082
Total	22,030,002	$6,021,222	25,966,122	$6,095,922	28,172,380	$6,658,350

State	1907		1908	
	Quantity	Value	Quantity	Value
New York . . .	9,642,178	$2,335,150	9,076,743	$2,136,738
Michigan . . .	10,786,630	2,231,129	10,194,279	2,458,303
Ohio	3,851,243	979,078	3,427,478	864,710
Kansas	2,667,459	962,334	2,588,814	882,984
Louisiana . . .	1,157,621	226,892	947,129	249,733
California . . .	626,693	302,940	899,028	374,828
West Virginia .	156,147	76,527	145,157	70,481
Texas	356,086	226,540	442,571	255,652
Utah	345,557	199,779	242,678	169,833
Idaho	1,600	2,040	1,114	1,413
Nevada	6,457	3,654	9,714	4,785
Oklahoma . . .	800	910	[1]	[1]
Other States . .	[4] 105,657	61,350	[5] 847,357	84,172
Total	29,704,128	$7,608,323	28,822,062	$7,553,632

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[1] Included in other States.
[2] Virginia, Pennsylvania, Oklahoma, Nevada, New Mexico, Massachusetts, and Idaho.
[3] Includes Virginia, Pennsylvania, New Mexico, and Massachusetts.
[4] Includes Pennsylvania, New Mexico, and Massachusetts.
[5] Includes New Mexico, Oklahoma, Pennsylvania, and Virginia.

The exports in 1908 were 53,253,739 lb., valued at $202,338, smaller than for several years. The imports for the same year amounted to 319,285,638 lb., valued at $444,690, this being less than any year since 1902.

WORLD'S PRODUCTION OF SALT FOR LAST YEAR AVAILABLE

COUNTRY	SHORT TONS	VALUE
United States (1907)	4,158,578	$7,608,323
United Kingdom (1907)	2,222,236	3,157,094
France and Algeria (1907)	1,373,906	3,823,523
German Empire (1907)	2,150,587	5,319,273
Japan (1904)	773,776	4,852,049
Italy (1907)	5,566,615	1,075,203
Austria-Hungary (1907)	435,409	9,764,835
Russia (1903)	1,828,646	3,652,074
Spain (1906)	597,422	782,407
India (1906)	1,296,674	1,916,092
Canada (1907)	72,697	342,315
Other countries (1907)	85,979	57,900
Total	15,340,553	$41,185,910

REFERENCES ON SALT

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BROMINE

Sources. — Bromine occurs in nature combined with some metals, as in the minerals Embolite, Ag (Cl, Br), Bromyrite (Ag Br), and Iodobromite (2 Ag Cl, 2 Ag Br, Ag I), which theoretically contain 25, 42.6, and 17.8 per cent respectively of bromine. None of these are commercial sources. Sea water contains about .06 gram per liter, and at Stassfurt, Germany, the mother liquor obtained from salt refining contains from 15 to 35 per cent bromine.

In the United States bromine is extracted from natural brines found at several geological horizons, but not all rock brines contain it, some, as those of New York State, being very low in it.

At the present time Ohio, West Virginia, Pennsylvania, and Michigan brines are used, the first bromine having been manufactured in 1846 at Freeport, Pennsylvania.

At Pomeroy and Syracuse, Meigs County, Ohio, and at Hartford and Mason, Mason County, West Virginia, it is obtained as a byproduct of the salt industry, the brine coming from the Pottsville horizon (Big Salt Sand).

A plant has been operated also at Pittsburg, Pennsylvania, obtaining the bromine from brines in the Pocono sandstone. That manufactured in Michigan comes from the Marshall sandstone of the Lower Carboniferous, the brine containing from .1 to .3 per cent bromine.

Uses. — Bromine is used for making bromides of potash, soda, and ammonia, for medicinal purposes and photographic reagents. A small amount is employed in the preparation of coal-tar colors known as Eosine and Hoffman's Blue. As a chemical reagent, it is utilized for precipitating manganese from acetic acid solutions, for the conversion of arsenious into arsenic acid, etc. It may also be used as a disinfectant when dissolved in water, and has been employed in gold extraction.

PRODUCTION OF BROMINE

PRODUCTION	QUANTITY IN POUNDS	VALUE	PRODUCTION	QUANTITY IN POUNDS	VALUE
1885	310,000	$89,900	1903	598,500	167,580
1890	387,847	104,719	1904	897,100	269,130
1891	343,000	54,880	1905	1,192,758	178,914
1895	517,421	134,343	1906	1,283,250	165,204
1900	521,444	140,790	1907	1,379,496	195,281
1901	552,043	154,572	1908	1,055,636	102,344

REFERENCES ON BROMINE

1. Merrill, U. S. Geol. Surv., Min. Res. 1904 : 1029, 1905. 2. Lane, Min. Indus., XVI : 123.

SODIUM SULPHATE

Occurrence and Distribution.—The hydrous sulphate, mirabilite or Glauber salt ($Na_2SO_4 + 10\,H_2O$), is a white saline material, which is collected on or near the surface of some alkaline marshes in desert regions. It may also be extensively deposited in some saline lakes, its precipitation preceding that of salt, and being affected more or less by the season of the year; for since it is much more soluble in warm than in cold water, the difference in temperature between summer and winter may cause its separation and re-solution (5). The phenomenon has been noticed in Great Salt Lake (4). Exposure to warm, dry air causes the mirabilite to lose its water and change to thenardite.

No production of sodium sulphate is recorded by the United States Geological Survey. It is known to occur at several localities in Wyoming (3). Deposits of some extent have also been noted in the lowest portion of the Carriso Plain, along the northeast boundary of San Luis Obispo County, California (6). In this lake, which remains practically dry, except in very wet seasons, there have been deposited a series of saline beds, whose chief constituent is sodium sulphate. The salt has been derived from the leaching of soft beds of conglomerate, sandstone, and shale in the surrounding hills. An analysis of the salt crust yielded: Insoluble, .40; Al_2O_3, .04; MgO, 1.66; CaO, .45; Na_2O, 40.50; K_2O, .28; H_2O, 3.65; SO_3, 46.12; Cl, 9.27; Total, 102.37; less oxygen, 2.09; = 100.28. The superficial deposit is said to be from 1 to 6 feet in depth, and is underlain by a supersaturated solution of the sulphate and water. Operations looking to the utilization of the deposit have been begun.

REFERENCES ON SODIUM SULPHATE

1. Attfield, Jour. Soc. Chem. Ind., Jan. 31, 1895. 2. Knight, Min. Indus., III : 651, 1895. 3. Knight, Wyo. Agric. Exper. Sta., Bull. 14, 1893. 4. Gilbert, U. S. Geol. Surv., Mon. I : 253, 1890. 5. Clarke, U. S. Geol. Surv., Bull. 330 : 186, 1908. (General.) 6. Arnold and Johnson, U. S. Geol. Surv., Bull. 380, 1909 (Calif.).

SODIUM CARBONATE

Sodium carbonate, or natural soda, is obtained by the evaporation of the waters of alkali lakes, or is found as a deposit on or near the surface of alkaline marshes in arid regions. It is usually a mixture of sodium carbonate and bicarbonate in varying proportions, as well as impurities such as sodium chloride, sodium sulphate, borax, and sodium nitrate.

Sodium carbonate has been obtained from Owens Lake in California. An analysis of the waters by Chatard yielded: SiO_2, .220; Fe_2O_3, Al_2O_3, .038; $CaCO_3$, .055; $MgCO_3$, .479; KCl, 3.137; NaCl, 29.415; Na_2SO_4, 11.080; Na_2CO_3, 26.963; $NaHCO_3$, 5.725. The soda is purified by fractional distillation. Soda is also known to occur in Oregon and Nevada.

REFERENCES ON SODIUM CARBONATE

1. Bailey, Calif. State Min. Bur., Bull. 24 : 95, 1902. 2. Chatard, U. S. Geol. Surv., Bull. 60 : 27, 1888. (Analyses.) 3. Russell, U. S. Geol. Surv., Mon. XI : 73, 1885. 4. Clarke, U. S. Geol. Surv., Bull. 330 : 189, 1908.

SODA NITER[1]

Soda niter, or Chile saltpeter ($NaNO_3$, with 63.5 per cent Na_2O_5 when pure), is found in San Bernardino and Inyo counties, California, along the shore lines marking the boundary of Death Valley in Eocene times (1). It occurs in peculiar rounded hills of Eocene clay, the niter being found as a layer near the surface or distributed through the clay. Very little soda niter is obtained from this source, and the main supply of this country continues to come from Chile, where extensive deposits are found in the desert region west of Iquique. There the niter (*caliche*) forms a bed 6 to 12 feet thick, under a cap of conglomerate (*costra*) 1 to 18 feet thick. The origin of this deposit is interesting, and has caused considerable discussion. One theory quite generally accepted is that the niter was formed primarily by the slow oxidation in air of guano or other nitrogenous organic matter in contact with alkali; a second theory refers its origin to the oxidation of organic materials and ammonia, by microscopic organisms known as nitrifying germs.

REFERENCES ON SODA NITER

1. Bailey, Calif. State Min. Bur., Bull. 24 : 139, 1902. 2. Clarke, U. S. Geol. Surv., Bull. 330 : 205, 1908. (Chemistry, analyses, origin.) 3. Penrose, Jour. Geol. XVIII : 1, 1910. (Chile.)

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[1] The term *niter*, when used alone, refers to potash niter.

BORAX

Borax Minerals (3, 4). — The chief minerals containing boron are borax, tincal, or sodium biborate, $Na_2B_4O_7$, 10 H_2O; colemanite, $Ca_2B_6O_{11}$, 5 H_2O; ulexite, $CaNaB_5O_9$, 8 H_2O; boracite, 2 $Mg_3B_8O_{15}$, $MgCl_2$. These minerals are found usually as incrustations in alkaline marshes, or in lake waters of arid regions, or as bedded deposits. In some localities boric acid is found in fumarolic vapors.

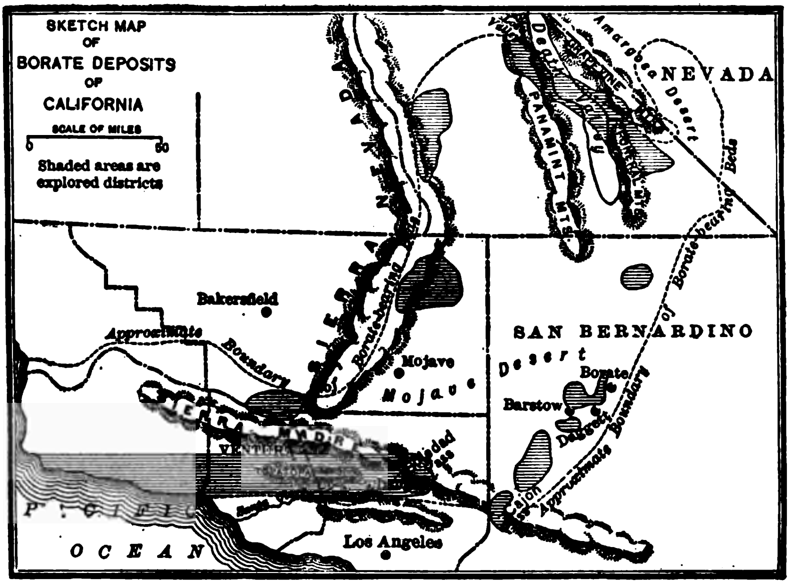

FIG. 67. — Sketch map of California borax localities. (*After Keyes, Amer. Inst. Min. Engrs.*, 1909.)

Distribution in the United States. — Deposits of borax have up to the present time been discovered only in California (1, 2, 5), Nevada, and Oregon (3, 8). Borax was originally obtained by evaporation from the waters of Clear Lake,[1] north of San Francisco, being produced in commercial quantities in 1864, and the solution was enriched by crystalline borax obtained from the marshes surrounding the lake. This and other lakes of California were worked until the discovery of large deposits of nearly pure borax in alkaline marshes of eastern California and western Nevada in the early seventies. Several refining plants were located at these marshes, and the product was sometimes hauled a hundred miles to the railroad. Increased production and importation from Italy, however, reduced the price and caused these plants to be abandoned.

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[1] An analysis of the solids of hot spring from sulphur bank on margin of Clear Lake yielded Cl, 16.49; I, .03; CO_2, 21.96; B_4O_7, 25.61; Na, 24.99; NH_4, 7.88; Al_2O_3, .40; SiO_2, 2.64. (U. S. Geol. Surv., Bull. 330 : 154.)

The discovery, in 1890, that the marsh borax was a secondary deposit, derived from easily accessible and extensive bedded deposits in the Tertiary lake beds of that region, revolutionized the industry.

The Tertiary clays (2, 5) in which the borax deposits are found occur mainly in southern California, but partly in Nevada (Fig. 67). They are exposed at intervals from Death Valley and the Nevada boundary, as far as the Pacific Ocean near Santa Barbara, north of Los Angeles. Daggett in San Bernardino County (Pl. XX, Fig. 2) was formerly the chief locality, but more important deposits have recently been discovered in Furnace Cañon and Santa Clara. In this region (Fig. 68), the borax, which forms a regular layer or layers, is interbedded with sands and clays, supposed by Campbell to have been deposited in a series of Tertiary lakes (2), but the beds are in many instances tilted, due to violent crustal movements, which interrupted sedimentation at intervals. Keyes estimates the section at 4000 to 5000 feet thick, but is not sure that all the borax beds occur at the same geologic horizon.

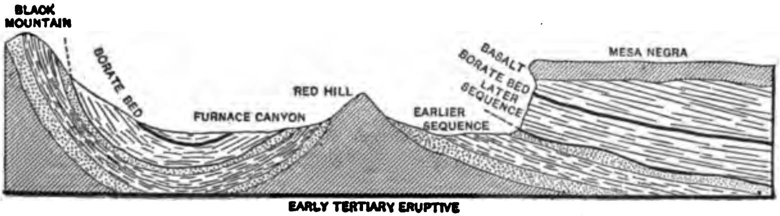

FIG. 68. — Cross section of Furnace Cañon, Calif., borate deposits. (*After Keyes, Amer. Inst. Min. Engrs.*, 1909.)

In Furnace Cañon, for example, the richer borate beds range from a few inches to 50 feet in thickness. The unweathered portions consist of bluish clays, thickly interspersed with milk-white layers, nodular bands, and nodules of crystallized colemanite or calcium borate, which is termed locally " high grade ore."

The " low-grade ore " consists of clays impregnated with fine particles of the borate mineral, and yielding, on leaching, from 10 to 25 per cent of anhydrous boric acid. Selenite not infrequently accompanies the coarse colemanite and in some places may be in excess.

In 1907 important deposits were discovered in Tick Cañon, Los Angeles County, which promise to be of great importance because of their proximity to the railroad.

Uses. — The borax-bearing minerals are utilized chiefly for the manufacture of borax and boracic acid. Borax is used in industrial chemistry, in medicine, and as a laboratory reagent. It is also employed in the assaying of gold and silver ores, in soldering brass, and welding metals.

Boric acid is used in the manufacture of borax, in colored glazes for decorating iron, steel, and metallic objects, in enamels and glazes for pottery, in making flint glass, as an antiseptic, and as a preservative for food. Chromium borate makes a green pigment used in calico printing, and manganese borate is sometimes employed as a drier in paints and oils. Borax is also extensively used in numerous cosmetics.

The chief refiners are the Pacific Coast Borax Company with works at Bayonne, New Jersey, and Alameda, California, and the Sterling Borax Company of San Francisco, California.

Production of Borax. — The California colemanite deposits form the main source of domestic supply, the output being derived from the counties of San Bernardino, Inyo, and Ventura. The marsh deposits of Nevada are no longer productive.

The production of borax in California from 1904 to 1908 was as follows, the values being based on the boric-acid content of the corresponding number of crude tons of colemanite or borate of lime.

YEAR	SHORT TONS	VALUE	YEAR	SHORT TONS	VALUE
1904	45,647	$698,810	1907	52,850	$1,121,520
1905	46,334	1,019,154	1908	25,000	975,000
1906	58,173	1,182,410			

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IODINE

Sources. — This element is known to occur in sea water, in mineral springs, and in a few rare minerals, such as the iodides of silver, copper, and lead. In the Chilean nitrate deposits it exists as lautarite [$Ca(IO_3)_2$] and as a double salt of calcium iodate and chromate [$Ca(IO_3)_2$, $CaCrO_4$]. Some Silesian zinc ores and some of the phosphate rocks of France show small percentages of the element. It has been found in the ashes of sea weeds, and in some oil-well waters, certain Pennsylvania ones carrying .5587 gram of calcium iodide per liter.

At present the entire production of iodine comes from two sources, viz., the ashes of sea weeds and the niter deposits of Chile.

REFERENCES ON IODINE

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CHAPTER VII

GYPSUM

Properties and Occurrence. — *Gypsum* (1, 4), the hydrous sulphate of lime ($CaSO_4, 2H_2O$), occurs most frequently in sedimentary rocks, interbedded with shales, sandstones, and limestones, and often more or less closely associated with rock salt. It is also found as surface deposits mixed with clay (*gypsite*) (11), or in the form of sand (5 Ariz.). The first two types are the most important commercially. It also occurs as efflorescent deposits, periodic lake deposits, in lumps and plates scattered through clays or shales, in veins, and in limited quantities in volcanic regions, especially in lavas (4). When occurring in bedded deposits (Pl. XXI, Fig. 2) it is often massive, of crystalline texture or earthy appearance, and of variable color, although most commonly white and gray.

Transparent, colorless forms, known as *selenite*, are found as veins or crystals in the massive gypsum, or as plates and crystals in many clays, shales, and limestones. This variety by itself never forms deposits of commercial importance, although selenite scales are sometimes plentifully scattered through the purer varieties. *Alabaster* is a pure white, fine-grained, massive variety, which is sometimes used for ornamental work.

Gypsum when pure contains 46.6 per cent sulphur trioxide, 32.5 per cent lime, and 20.9 per cent water. It has a specific gravity of 2.3, and a hardness of 1.5 to 2. It is therefore sufficiently soft to be easily scratched with a knife or even by the thumb nail.

Anhydrite differs from gypsum chemically in the absence of water, but changes to it on exposure to the air and moisture. In some cases it may have been derived from gypsum. When present, it may occur as veinlets, beds or masses in the gypsum deposit; indeed, its irregularity of occurrence is at times puzzling (Pl. XXI, Fig. 1).

Anhydrite contains 41.2 per cent lime, 58.8 per cent sulphur trioxide. Its specific gravity is 2.8 to 2.9 and its hardness 3 to 3.5. As it is of no commercial value, it may cause trouble in quarrying, if present in large quantities.

So far as published accounts go, anhydrite does not appear to be very abundant in the gypsum deposits of the United States. It is not uncommon in the Virginia mines, and Lane notes its occur-

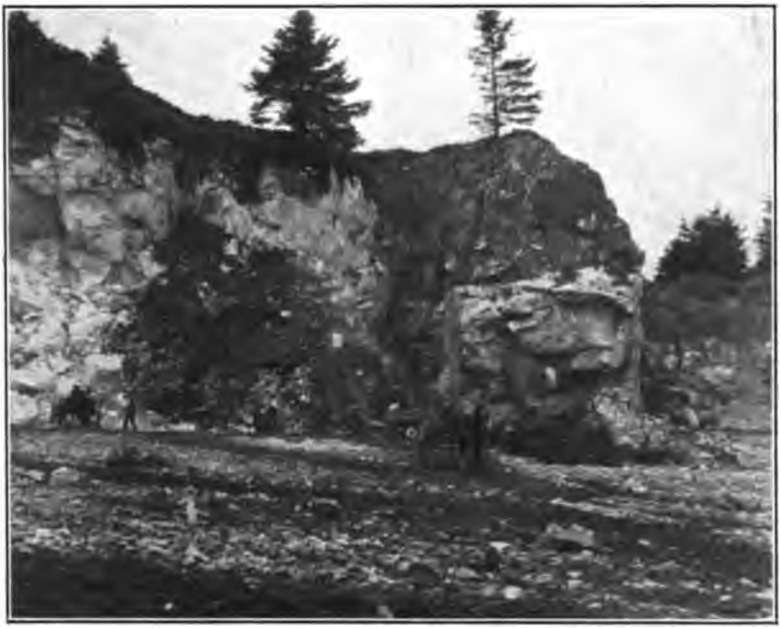

FIG. 1. — View in a Nova Scotia gypsum quarry, showing large mass of anhydrite. The anhydrite forms the buttress on right of quarry face, and is not removed. Good gypsum occurs on either side of it. (*H. Ries, photo.*)

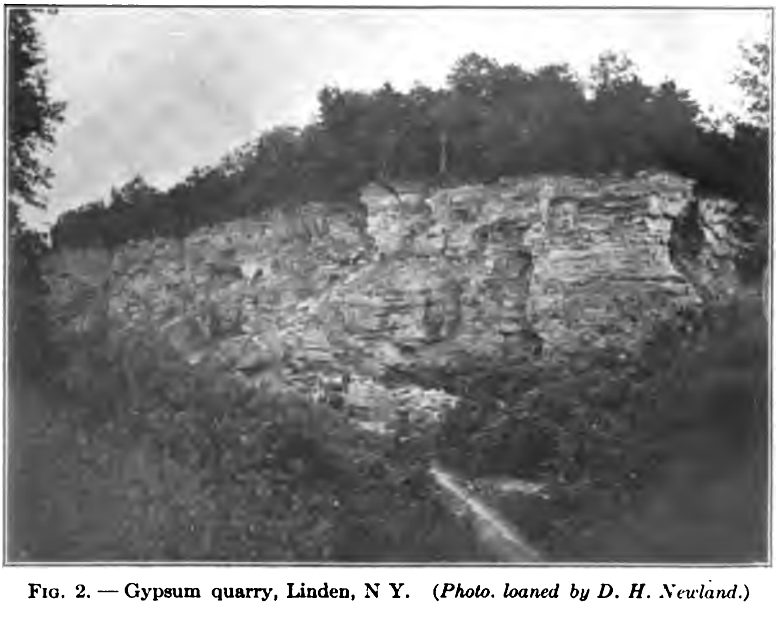

FIG. 2. — Gypsum quarry, Linden, N Y. (*Photo. loaned by D. H. Newland.*)

rence in the deeper-lying parts of the Michigan gypsum series. Some extensive beds also occur in Oklahoma. Scattered irregular masses and beds are abundant in some of the New Brunswick and Nova Scotia gypsum areas.

Impurities in Gypsum.—Clay is probably the commonest impurity, and occurs either uniformly distributed through the gypsum, or else in layers. Lime carbonate is often present, though rarely in large amounts. The same may be said of magnesia, silica, and iron oxide.

Origin of Gypsum (1, 4). — Gypsum is widely distributed both geographically and geologically, being found in various horizons from the Silurian to the Recent. Most beds of this substance have no doubt been formed by the evaporation of salt water either in inland seas or else in arms of the ocean, the process of precipitation having been discussed in the chapter on *Salt*. As gypsum separates from sea water after 37 per cent of the water is evaporated, while salt precipitates only after 93 per cent has been removed, it is evident that gypsum beds may be deposited without salt. This may also explain why gypsum is more widely distributed than salt; and the fact that the percentage of gypsum in salt water is much less than that of salt probably accounts for its usual occurrence in the thinner deposits.

The conditions under which anhydrite forms do not appear to be thoroughly understood. According to Vant Hoff and Weigert, anhydrite forms from gypsum in sodium chloride solutions at 30°C., while in sea water the transformation takes place at 25°C. (Quoted by Clarke 4). Lane (12) believes that all calcium sulphate precipitated at a greater depth than 500 feet is really anhydrite rather than gypsum. Indeed, some believe that perhaps much of the gypsum now found was originally anhydrite.

If the change was brought about by penetrating surface waters, it might account for the irregularity of occurrence of the anhydrite in the gypsum. That such a transformation may extend to a considerable depth is shown by the deposits at Bex, Switzerland (4), where the alteration has reached a thickness of 60 to 100 feet.

Gypsum may also be formed by the decomposition of sulphides, such as pyrite, and the action of the sulphuric acid thus liberated on lime carbonate. Small quantities are formed in volcanic regions through the action of sulphuric vapors on the lime of volcanic tuffs or other rocks (4).

Gypsite, or gypsum dirt, is an earthy or sandy variety of gypsum forming a surface deposit in Kansas (11) and other western states

(20, 23), which, in spite of its impure appearance, may run high in calcium sulphate. It is believed to be a deposit either in the soil or in shallow lakes supplied by springs whose water has dissolved the calcium sulphate from gypsum beds or other rocks. During its precipitation by the second method, its impure character is caused by its becoming mixed with clay or sand washed in from the land.

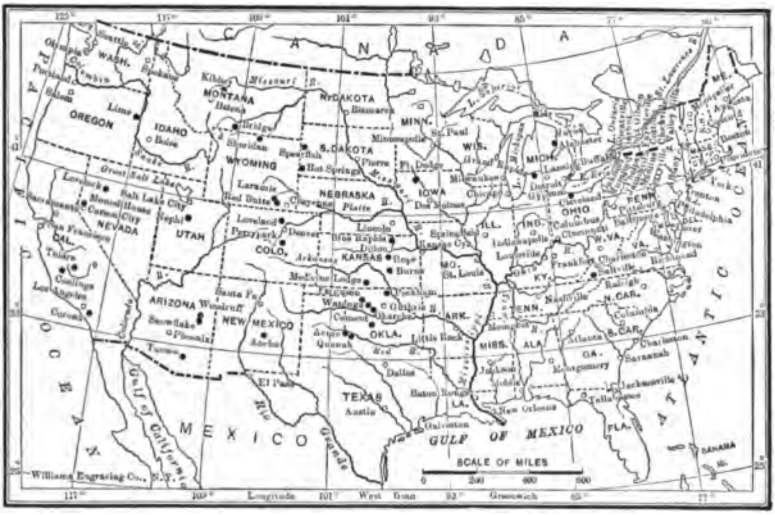

FIG. 69. — Map showing gypsum-producing localities of the United States. (*After Adams, U. S. Geol. Surv., Bull.* 223.)

Distribution in the United States (Fig. 69). — Eighteen states and territories are producers of gypsum, although three of these — New York, Michigan, and Iowa — produce over 50 per cent of the total quantity mined.

The wide geologic range of gypsum deposits in the United States can be seen from the following table: —

STATE OR TERRITORY	AGE	STATE OR TERRITORY	AGE
Alaska	Permian or Triassic	Nevada	Triassic
Arizona	Triassic and Tertiary (Pliocene)	New Mexico	Permian
Arkansas	Tertiary	New York	Silurian
California	Tertiary	Ohio	Silurian
Colorado	Permian	Oklahoma	Pleistocene Permian
Iowa	Permian	South Dakota	Permian
Kansas	Pleistocene Permian	Texas	Permian
Michigan	Lower Carboniferous	Utah	Jurassic
Montana	Lower Carboniferous	Virginia	Carboniferous
		Wyoming	Triassic

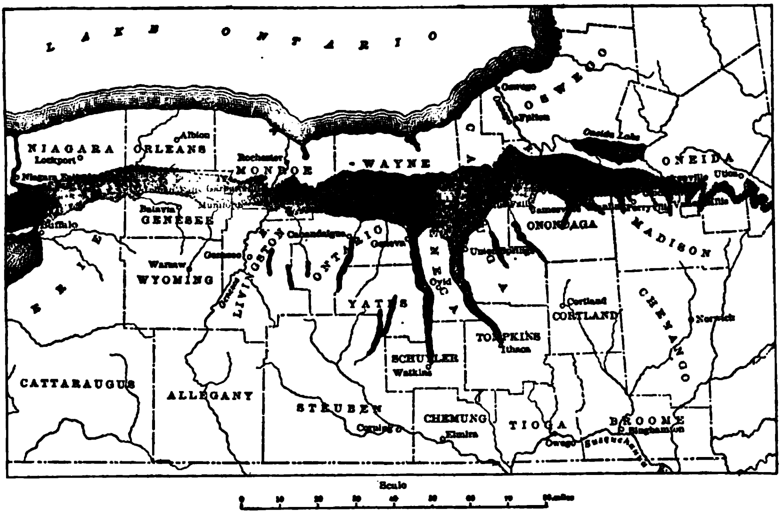

FIG. 70. — Map of New York showing outcrop of gypsum-bearing formations. (*U. S. Geol. Surv., Bull.* 223.)

New York (13, 14) — In this state, which is one of the three largest producers, the gypsum occurs as rock gypsum, interbedded with shales and shaly limestones of Salina (Silurian) age. The beds, several of which may occur in the same section, are lenticular in shape, but of such horizontal extent that in any one quarry they appear of uniform thickness (Pl. XXI, Fig. 2). In most quarries they range from 4 to 10 feet, and their general dip is southward, but there are local irregularities. The main gypsum deposits occur in the upper part of the Salina, while the salt beds lie lower down in this formation. The area of outcrop of the Salina is shown in Fig. 70. The gypsum deposits, which occur mostly in the central part of the state, are usually impure, except in Genesee County. Figure 71 shows a not uncommon mode of occurrence.

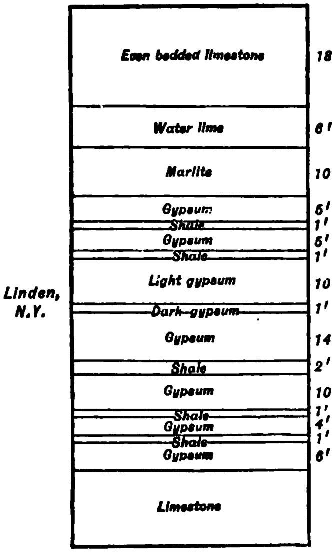

FIG. 71. — Section in gypsum deposit at Linden, N.Y. (*After Eckel, U. S. Geol. Surv., Bull.* 223.)

Michigan (12). — All the Michigan

gypsum is rock gypsum and of high purity. There are two important areas, one being in the vicinity of Grand Rapids, and the other at Alabaster on Saginaw Bay (Pl. XXII, Fig. 1), both in beds of Lower Carboniferous age. These beds, known as the Grand Rapids formation, surround the Michigan coal basin,[1] and carry the gypsum in their lower part. At Grand Rapids, the gypsum beds, which are interstratified with shale and limestone, run from 6 to 12 feet in thickness, and are worked either by quarrying or underground chambers. At Alabaster, Iosco County, the gypsum, which immediately underlies the glacial drift, is 23 feet thick.

A third, possibly productive, area is near St. Ignace on the upper peninsula, but there the gypsum occurs in the Salina or Monroe group (Silurian).

Iowa (10). — Important deposits are found in this state in an area of about 25 square miles in Webster County, especially near Fort Dodge. The gypsum, which is presumably of Permian age, rests on the Coal Measures, or the St. Louis limestone (Lower Carboniferous), and is covered by glacial drift, but in places is overlain conformably by red shales. It varies from 3 to 30 feet in thickness, with an average of 16 feet, and much of it is sufficiently white for stucco.

Kansas. — Gypsum (11) is found occurring as rock gypsum, or as gypsite, the deposits forming a belt extending across the central part of the state in a northeast-southwest direction, and includes three important areas, viz. Northern, or Blue Rapids, in Marshall County, Central, or Gypsum City, in Dickinson and Saline counties, and Southern, or Medicine Lodge, in Barber and Comanche counties. The beds of rock gypsum are of Permian age, interbedded with red shales, those at the southern end of the belt being stratigraphically 1000 feet higher than those at the northern end.

The gypsite or gypsum dirt, which is of more recent age, is found in the central area, as well as at a number of other localities. The spring waters which have supplied it have leached the calcium sulphate either from the gypsum beds or the red shales. The gypsite is found especially in the central area, and the deposits were the first of their kind worked in the United States.

The product is used for fertilizer and cement plaster, and much is also used for making Keene's cement.[2] The rock, which is quarried especially in the northern and southern areas, is white in color, and may range from 8 to 16 feet in thickness.

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[1] It is interesting to note that wells sunk in the central portion of the basin show that the gypsum passes into anhydrite, indicating that if the gypsum is of primary character it was deposited around the borders of the old interior sea.

[2] A cement made by burning gypsum at high temperatures, and then treating it with alum or other chemicals.

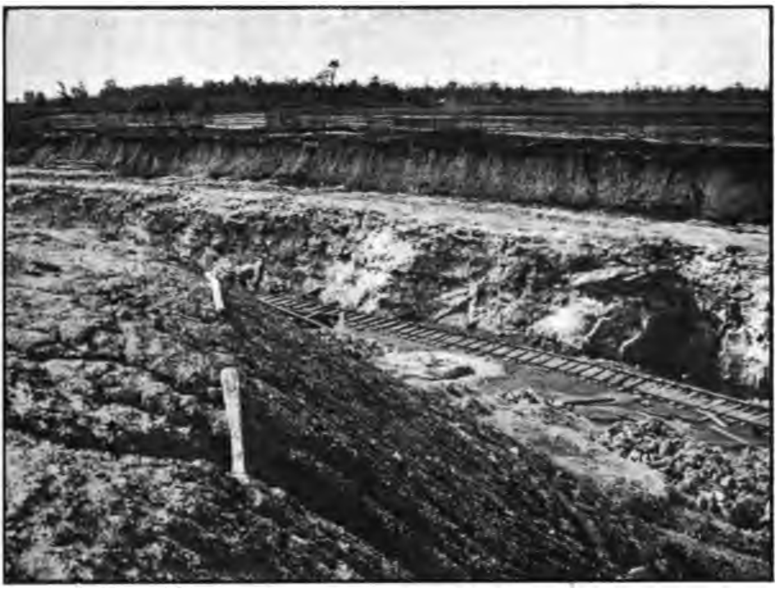

FIG. 1. — Gypsum quarry, Alabaster, Mich. Shows gypsum overlain by glacial drift. The dump in foreground is overburden removed from gypsum. (*Photo., A. C. Lane.*)

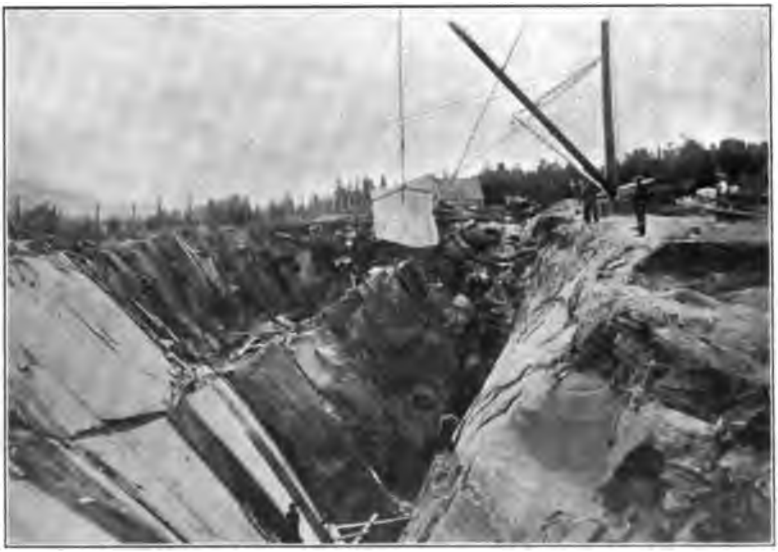

FIG. 2. — View in scythestone quarry, Pike Station, N. H. (*Photo. loaned by Pike Mfg. Co.*)

Virginia. — Gypsum is also found in beds of Lower Carboniferous age in the Holston Valley of southwestern Virginia (22), the deposits occurring in shales, between Carboniferous (Greenbrier limestone) and Siluro-Devonian sandstones (Fig. 63). The section is faulted up against the Cambro-Silurian limestones, on the southeast, and both the gypsum and salt deposits seem to be limited to a narrow belt bordering on this fault.

The gypsum occurs in bowlder masses in gray and red clays, and is interesting because of the abundant but irregular occurrence of anhydrite, which grades into the gypsum. The rock is mined partly by underground workings, and some of the beds are fully 30 feet thick. The product is used for land and wall plaster.

In Ohio gypsum has been obtained from the lower Helderberg beds of Ottawa County, 10 miles west of Sandusky. The material occurs at different horizons, the beds being bent into rolls, the main ones having a thickness of about 12 feet (15, 20).

Other Occurrences. — Additional occurrences are known in Wyoming (23, 24), Utah (21), Nevada (20), California (8), Montana (20), Idaho (20), Colorado (9, 20), South Dakota (17–19), Oklahoma (16), Texas (20), and Arizona (7, 20). In the last, as well as in New Mexico, there are found important deposits of gypsum sand, composed of gypsum grains broken down by stream action and water from rock gypsum outcrops, and then gathered into hills or dunes by wind action. Some of these dunes are more than 100 feet high. The utilization of these sands in Otero County, New Mexico, was begun in 1908.

Gypsum (6) of Permian or Triassic age is known to occur on Chichagof Island in southeastern Alaska. The beds, which are folded and steeply tilted, have been extensively developed during the last few years and shipped to Tacoma for preparation. It comes into competition with similar material from the western states.

Analyses of Gypsum. — The following analyses indicate the composition of gypsum from different localities in the United States. They cannot all be guaranteed as being of average character, and serve mainly to show variation in composition : —

	PURE GYPSUM	DILLON KAS.	ALABASTER MICH.	GRAND RAPIDS MICH.	SALTVILLE VA.	GYPSITE MARLOW I. T.	GYPSITE BURNS KAS.	GYPSITE SALINA KAS.	GYPSITE DILLON KAS.
$CaSO_4$	79.10	78.40	78.51	76.26	72.06	59.46	67.91	34.38	56.58
H_2O	20.90	19.96	20.96	20.84	21.30	16.59	17.72	8.50	15.16
SiO_2	—	.35	.05	tr.	1.68	10.67	2.31	34.35	17.10
Al_2O_3 and Fe_2O_3 .	—	.12	.08	.54	1.95	.60	.37	4.11	2.04
$CaCO_3$	—	.56	—	n.d.	—	10.21	11.71	8.14	7.71
$MgCO_3$	—	.57	.11	n.d.	—	1.10	.52	10.52	1.24
	100.00	99.96	99.71	97.64	96.99	98.63	100.53	100.00	99.83

	Onondaga, N.Y.	Ft. Dodge, Ia.	Sandusky, O.
$CaSO_4$	73.92	73.44	78.73
H_2O		20.76	19.70
SiO_2	4.64		.91
Al_2O_3		.65	.60
Fe_2O_3			
$CaCO_3$	21.44	—	—
MgO	—	—	.54

Uses (1 *a*). — Gypsum is sold either in the ground, uncalcined condition, or after calcining and screening. In the former state its chief value is as a fertilizer, it being marketed under the name of land plaster, which is also used as a disinfectant.

In its calcined form, gypsum is known as *plaster of paris* and has the following uses, dependent on its property of hardening or setting when mixed with water: stucco, plastering for walls, whitewash, pottery molds, statuary, and dental purposes, as a deodorizer, for crayons, and as a retarder of fermentation and absorbent of water in wines.

An important use is as a retarder in Portland cement, large quantities being sold for this purposes. It is also employed as a bed for rolling hot glass.

Calcining Gypsum. — When heated to 250° F., gypsum loses a portion of its water of hydration, but if finely ground has the property of recombining with it. If heated to 300° F. to 400° F., it loses this power and is said to be *dead-burned.* In addition to dehydration, burning also breaks up the crystals into minute particles. The *set* is due to the formation of a crystalline network of the rehydrated grains.

Since calcined gypsum sets in from 6 to 10 minutes, some retarding material, such as organic matter from slaughter-house refuse, is often added to it, and thus the setting process may be delayed from 2 to 6 hours. Those plasters which set slowly are termed *cement plasters.*

The following analyses show the composition of (1) uncalcined gypsum; (2) the calcined rock; and (3) the plaster after it has taken up water and set. From these it will be seen that the plaster takes up the amount of water lost in calcination.

SERIES OF ANALYSES SHOWING CHANGES IN GYPSUM DURING BURNING AND AFTER SETTING

	Crude	Finished	Set
SiO_2 and Insol. res.	12.29	14.31	12.03
Fe_2O_3 and Al_2O_3	2.27	2.16	1.62
CaO	29.67	33.53	30.05
MgO	.78	.91	.61
SO_3	34.87	39.85	35.73
CO_2	3.52	4.11	3.55
H_2O	16.07	4.81	16.38

Though the softness of gypsum prevents its general employment as a building material, the pure white, massive varieties, known as *alabaster*, have been used for statuary, basins, vases, and other objects for interior decoration. Gypsum is also used to weight fertilizers, and as an absorbent of organic materials in them; as a flux in the manufacture of glass and porcelain; and, under the name of "*terra alba*," as an adulterant of foods and medicinal preparations.

Production of Gypsum.—Michigan, New York, and Iowa are the leading producers, but other states contribute considerable amounts.[1]

PRODUCTION OF GYPSUM IN THE UNITED STATES IN 1907 AND 1908 BY STATES AND USES, IN SHORT TONS

STATE	TOTAL MINED	SOLD CRUDE		SOLD CRUDE, GROUND, AS LAND PLASTER		SOLD AS CALCINED PLASTER		TOTAL VALUE
		Quantity	Value	Quantity	Value	Quantity	Value	
1907								
Alaska, Colorado, New Mexico, South Dakota, and Utah	96,389	13,349	$53,961	1;221	$4,884	72,872	$343,961	$402,806
California, Nevada, and Oregon	80,879	20,902	38,302	6,161	28,288	49,860	227,456	294,046
Iowa	251,874	17,272	24,837	1,562	4,278	162,965	701,268	730,383
Kansas	155,980	27,211	33,572	3,395	6,364	96,347	374,330	414,266
Michigan	317,261	36,543	56,681	15,500	23,981	197,666	600,689	681,351
New York	324,507	101,721	196,426	5,716	14,687	145,132	589,112	800,225
Ohio and Virginia	202,253	4,473	9,399	13,296	33,359	146,565	626,779	669,537
Oklahoma and Texas	282,461	11,075	11,049	——	——	223,254	813,568	824,617
Wyoming	40,144	——	——	——	——	30,640	125,033	125,033
	1,751,748	232,546	$424,227	46,851	$115,841	1,125,301	$4,402,196	$4,942,264
1908								
Alaska, Arizona, Colorado, Idaho, New Mexico, South Dakota, and Utah	129,440	19,863	$72,205	1,573	$3,890	101,274	$416,254	$492,349
California, Nevada, and Oregon	93,794	3,282	8,935	4,195	17,151	64,775	345,652	371,738
Iowa	240,270	19,960	26,429	1,984	3,676	158,043	535,540	565,645
Kansas	130,184	24,064	27,047	3,162	5,679	80,523	248,613	281,339
Michigan	327,810	40,324	53,673	11,414	13,381	192,403	424,874	491,928
New York	318,046	95,146	171,747	5,712	14,255	160,930	574,757	760,759
Ohio and Virginia	178,904	9,260	19,988	9.632	33,591	125,167	426,426	480,005
Oklahoma and Texas	272,193	[1] 14,362	16,721	——	——	216,350	583,141	599,862
Wyoming	31,188	——	——	——	——	26,152	94,935	94,935
	1,721,829	226,261	$396,745	37,672	$91,623	1,125,617	$3,650,192	$4,138,560

[1] Includes a small quantity of ground material from Texas.

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[1] Owing to the complexity of tabulation adopted by the United States Geological Survey, the state figures are given for 1907 and 1908 only.

Production of Gypsum in the United States, 1904–1908
classified as to Uses

	Sold Crude			Sold Crude, Ground, as Land Plaster			Sold as Calcined Plaster			Total Value
	Quantity in short tons	Value	Average price per ton	Quantity in short tons	Value	Average price per ton	Quantity in short tons	Value	Average price per ton	
1904 . .	56,137	$61,234	$1.09	70,167	$142,490	$2.03	665,340	$2,580,601	$3.88	$2,784,325
1905 . .	67,105	106,041	1.58	40,196	74,280	1.85	736,708	2,848,906	3.87	3,029,227
1906 . .	186,999	460,545	2.46	62,671	157,292	2.50	899,581	3,220,138	3.58	3,837,975
1907 . .	232,546	424,227	1.82	46,851	115,841	2.47	1,125,301	4,402,196	3.91	4,942,264
1908 . .	226,261	396,745	1.75	37,672	91,623	2.43	1,125,617	3,650,192	3.24	4,138,560

The imports for 1908 were valued at $354,403.

World's Production of Gypsum

Country	Short Tons	Value	Country	Short Tons	Value
France (1907) . . .	1,547,560	$2,544,819	German Empire (1904)	25,095	$17,307
United States (1907) .	1,751,748	4,942,264	Algeria (1907) . . .	29,101	75,907
Canada (1907) . . .	340,964	575,701	Cyprus (1906) . . .	23,069	55,658
Great Britain (1906) .	252,030	362,761			

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CHAPTER VIII

FERTILIZERS

UNDER this term are included a number of mineral substances, limestone (p. 139), marl (p. 143), gypsum (p. 178), phosphate of lime, greensand, guano, kainite (K_2SO, $MgSO_4$, $MgCl_2$, 6 H_2O) (p. 160), and niter (p. 173), which are of value for adding to the soil to increase its supply of plant food and also in some cases correct its physical condition. Some of these have other uses as well, and have been discussed elsewhere on those pages indicated by the numbers following them in the foregoing lines.

Phosphate of Lime. — This occurs both as crystalline phosphate of lime, or apatite, and amorphous phosphate of lime, or rock phosphate.

Apatite (6, 8). — This mineral when pure contains about 90 per cent tricalcic phosphate, and 10 per cent calcium fluoride, which may be replaced by calcium chloride. It is widely distributed in some igneous and metamorphic rocks, especially granites, gneisses, and some crystalline limestones, but rarely in sufficient quantity or in sufficiently concentrated masses to render its extraction profitable, at least while the supply of amorphous phosphate lasts. So, competition with rock phosphate has restricted mining to a few localities where it is associated with other valuable minerals.

In the United States apatite has been produced for several years at Mineville, N. Y. (7) where it occurs disseminated in small grains through the magnetite, forming sometimes as much as 5 per cent of the ore. In the process of magnetic separation the apatite is removed as tailings, the first grade of these carrying about 60 per cent tricalcium phosphate, and the second about 30 per cent. They are used in fertilizer manufacture.

A unique as well as extensive occurrence of phosphatic material is found at two localities in Nelson (figured under Titanium) and Roanoke counties, Virginia. The rock which Watson has named *Nelsonite* (8 *a*) consists of a hard granular aggregate of white apatite and black ilmenite, and forms a dike-like mass in gneisses and schists. The commercial value of this material as a source of phosphate remains to be proven.

Amorphous Phosphates. — These, though composed chiefly of phosphate of lime, also carry variable quantities of other substances. (See table, p. 196). They occur (1) as concretionary bodies in consolidated rocks; (2) as beds; (3) as irregular rocklike masses; and (4) as nodular masses of varying size, often scattered through unconsolidated beds. As is shown in the following descriptions, amorphous phosphates occur in various geological horizons, from the Silurian to Tertiary, and in several states, though most of the domestic supply at present comes from Florida, Tennessee, and South Carolina.

Florida (13, 25). — This state is at present the most important phosphate producer, although the full extent and value of the deposits were unsuspected until the discovery of large beds along the Peace River in 1887. The phosphate deposits which are associated with Tertiary limestones of various horizons from the Eocene to the Pliocene form a curved belt, beginning west of the Appalachicola River and extending east and then south through Dunnellon, and approximately as far as Punta Gorda (Fig. 72). The topography varies from gently rolling to flat pine lands and swampy areas, the general elevation being under 75 feet. Eldridge recognizes four types of phosphates in this area, viz., hard rock, soft rock, land pebble, and river pebble. Of these the *hard rock phosphate* (Pl. XXIII, Fig. 1) is the richest, and has had more influence in the rapid development of the district. It lies in pockets of irregular occurrence and extent, and rests usually on limestones of Lower Oligocene (Tertiary) age. The material is of hard, massive, close-textured character, variable color, and often contains irregular cavities which show a secondary deposition of phosphate. Accompanying the hard rock in some places is a second type, the *soft phosphate*, which is evidently a disintegration product. Bowlders of hard phosphate are sometimes

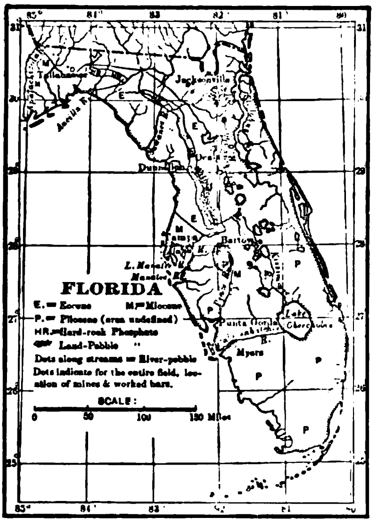

FIG. 72. — Map of Florida phosphate deposits. (*After Eldridge, Amer. Inst. Min. Eng., Trans. XXI.*)

PLATE XXIII

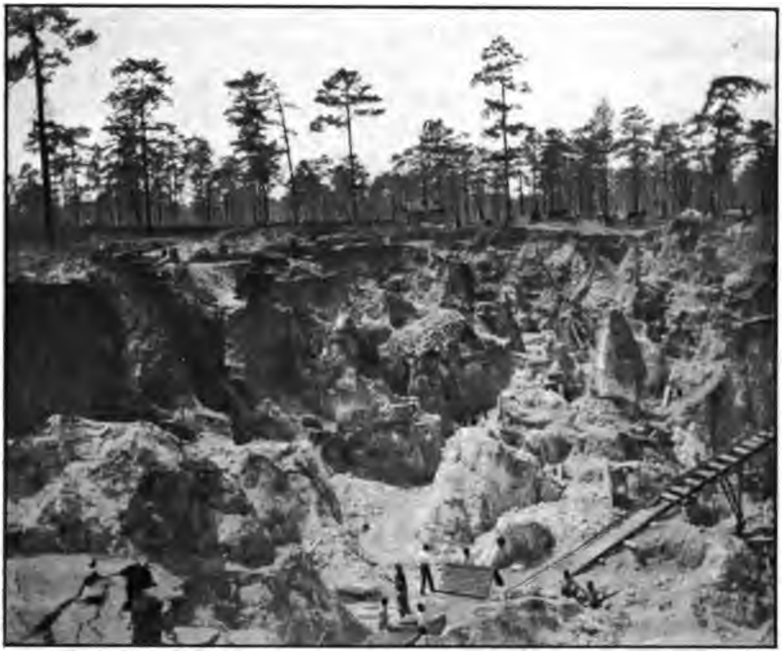

FIG. 1. — Rock phosphate mine near Ocala, Fla. (*Photo., A. W. Sheafer.*)

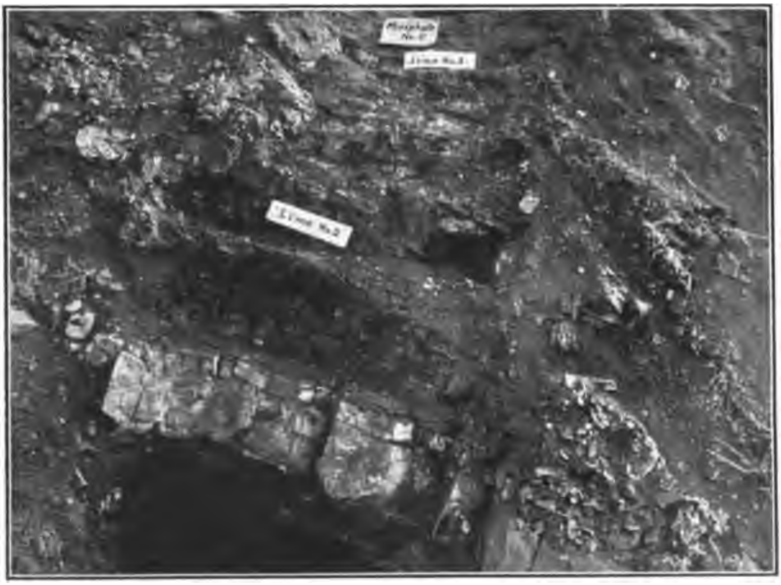

FIG. 2. — Phosphate beds, Montpelier, Ido. Shows the alternating layers of limestone and phosphate. (*W. F. Ferrier, photo.*)

embedded in a matrix of soft phosphate, and also in sands and clays overlying the Eocene limestone. In the Miocene it is also found at many places as a bedded deposit. While the hard rock has an average of a little over 36.65 per cent of phosphoric acid, the soft phosphate rarely averages over 22.90. The former is commonly sold under a guarantee of 77 per cent bone phosphate.

The land pebble or matrix rock is made up of pebbles of varying size, shape, and color, and composed either (1) of earthy material with fossils, quartz grains and pisolitic grains of phosphate, or (2) of pebbles closely resembling the hard-rock phosphate. To render it marketable, the pebbles, which average 32.06 per cent phosphoric acid, have to be freed from the matrix by washing and screening. The unit composition of sale for land pebble is 68 per cent of the bone phosphate and 3 per cent of the combined oxides of iron and alumina, with moisture not above 3 per cent.

The river pebble consists of phosphate pebbles, having a blue, black, or dark gray surface, and mixed with sand, bones, and teeth. It is found in the present as well as in ancient river channels, in the latter case being covered by coastal sands. That found in the Peace River district averages 28.40 per cent phosphoric acid.

All the above-mentioned types, with the exception of the soft phosphates, are found underlying more or less separate regions (Fig. 72).

Origin.—The origin of the Florida phosphates has been a puzzling problem to geologists. Eldridge (13) has proposed two theories: (1) that they have been derived by the leaching of guano and bone beds, and the deposition of the phosphate in the underlying limestone, either by precipitation in its pores or replacement of the lime carbonate; (2) that they are due to the solution of the limestone and consequent concentration of the less soluble phosphate of lime which was originally disseminated through the rock.

At a later date underground waters may have removed the limestone from around the phosphate deposits, leaving them as bowlders, which, at a still later period, were rounded by water currents which also deposited sand around them.

The land pebble and river pebble probably represent nodules of a highly phosphatized marl, formed in limestone, pebbles, or shell casts, by segregation of the lime phosphate contained in the limestones. Subsequent solution of the lime carbonate set free these nodules, some of which became concentrated as stream gravels.

South Carolina. — Phosphate is found both on the land and in the river bottoms in a belt about 60 miles long lying inland from Charleston and Beaufort (8, 20, 22). The phosphate, which rarely averages much over one foot in thickness, is commonly of nodular character, and often contains many bones and teeth. The presence of these animal remains, including both land and marine forms, has given rise to the belief that the deposits were caused by the accumulation of bones and excrements along a shore line, probably of Upper Miocene (Tertiary) age. Leaching of these remains may have permitted a later replacement of limestone or the formation of phosphatic concretions in swamp bottoms.

Two forms are recognized, viz. land rock and river rock. The former ranges from 1 to 3 feet in thickness and is overlain by greensand marl. The river rock is little more than water-worn fragments of the first type, and is mined from the river channels.

The South Carolina phosphate rock was worked as early as 1867, and the production increased up to 1893, but since then it has fallen off almost steadily.

Tennessee (14–16, 18, 23, 25). — Since the recognition, in 1893, of considerable quantities of high-grade phosphates in western middle Tennessee (Fig. 73), there have been important developments of the deposits. The phosphate areas lie mainly in Maury,

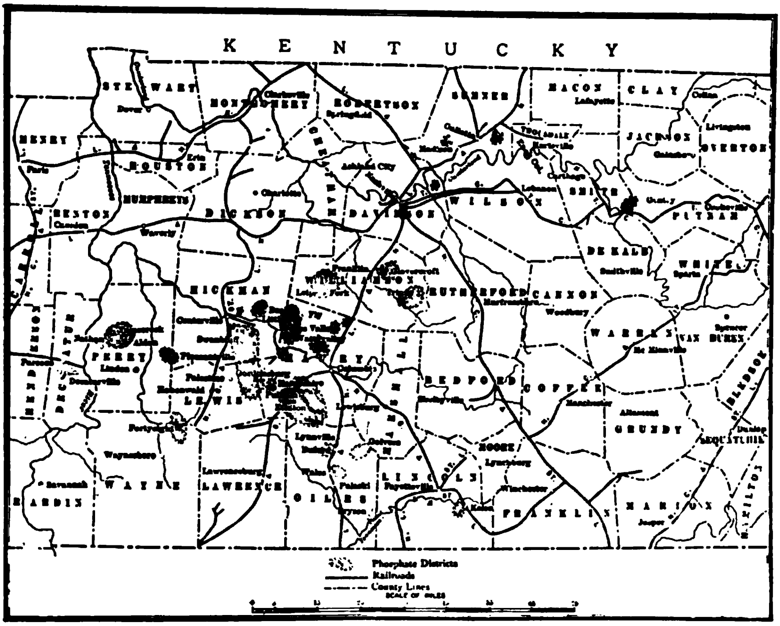

Fig. 73. — Map showing distribution of phosphates in Tennessee. (*After Ruhm, Eng. and Min. Jour., LXXXIII.*)

Hickman, Perry, and Lewis counties, but others are known in Giles, Williamson, Davidson, Sumner, and Decatur counties (Fig. 73).

Three types of phosphate deposits are recognized. The first is brown residual phosphate, occurring mainly along Duck River in Maury County. The material is of Ordovician age, and has been formed by the leaching of phosphatic limestones, the phosphate remaining as a residual deposit, whose thickness is from 2 to 8 feet.

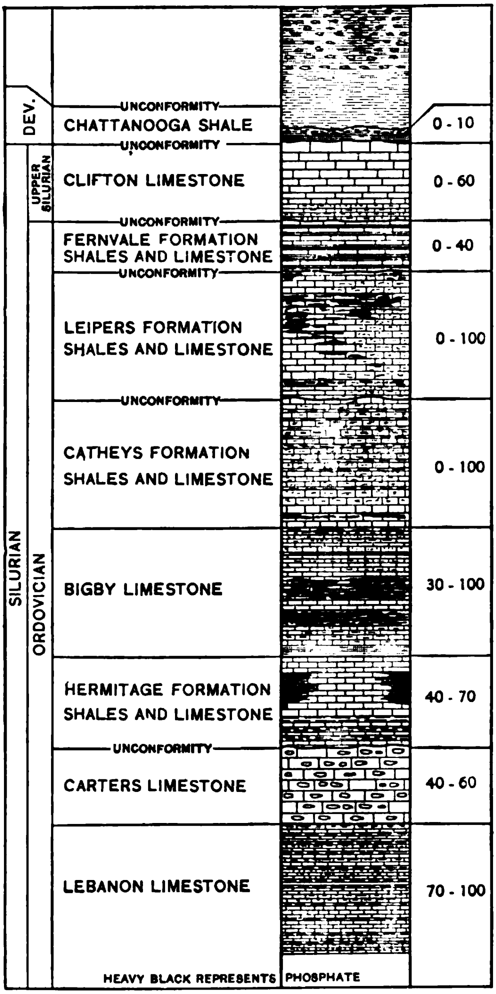

FIG. 74. — Vertical section showing geologic position of Tennessee phosphates. (*After Hayes.*)

A second type of black or blue color occurs either in beds or nodules. The bedded material, which is of Devonian age, varies from oölitic through compact and conglomeratic to shaly forms and is underlain either by gray Devonian sandstone or by blue Silurian limestone, and capped by black shale.

This type occurs in seams varying from 1 to 50 inches in thickness, although the high-grade material rarely exceeds 20 inches. Its phosphate of lime content ranges from 30 to 85 per cent. A nodular variety occurs in a greensand formation overlying the black shale, and while the nodules carry about 60 per cent lime phosphate, they are not workable except in connection with the bedded rock. Both types are believed to be chemical precipitates on the floor of the Devonian sea.

The third group includes white phosphate of post-Tertiary

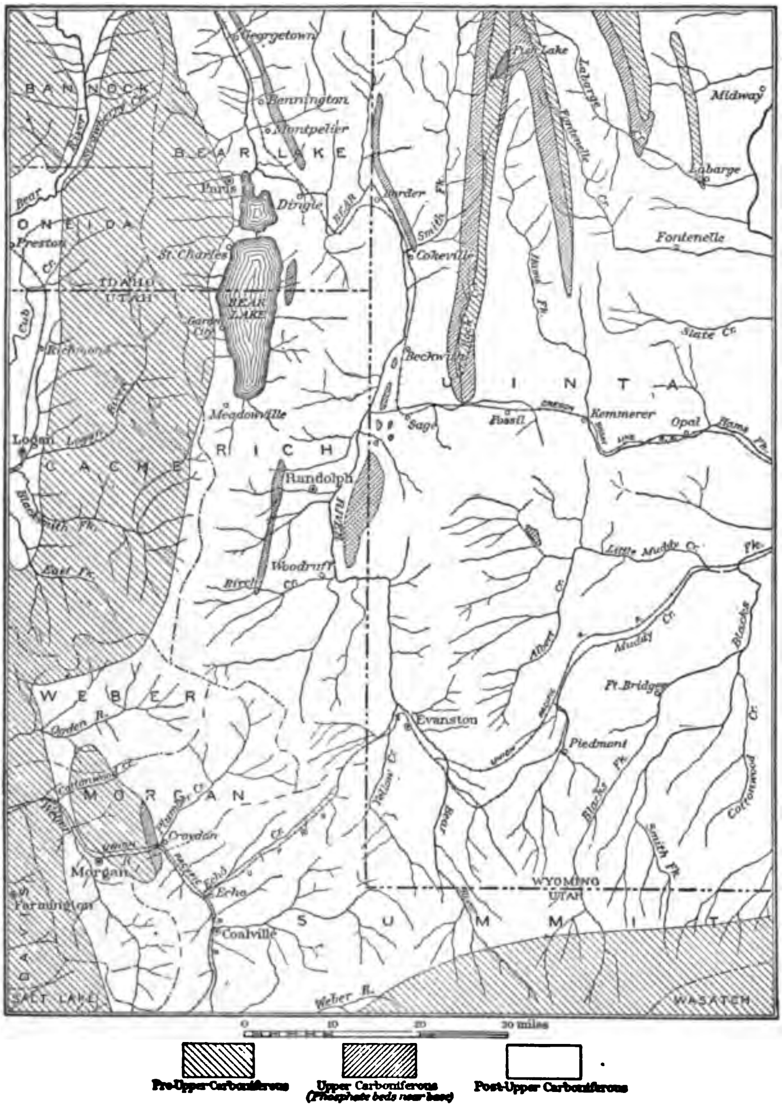

FIG. 75. — Map of parts of Idaho, Wyoming, and Utah, showing localities of Upper Carboniferous rocks containing phosphate beds. (*After Weeks and Ferrier, U. S. Geol. Surv., Bull.* 315, 1906.)

age, occurring in three conditions; namely, stony, brecciated, and lamellar.

In the stony phase the phosphate has been deposited in a siliceous limestone, replacing the lime. It alternates with beds of stony chert, and contains usually only about 50 per cent lime phosphate, but is not worked. The brecciated form, which is the most abundant, consists of angular fragments of Carboniferous chert in a phosphate matrix. These chert fragments vary from 3 to 4 inches in diameter. The lamellar variety was deposited in caverns in the Silurian limestone, and is therefore of irregular shape and extent. Since its deposition the limestone has weathered to a residual clay, in which the phosphate masses occur.

White phosphate has thus far been found only in Perry and Decatur counties, and may run as high as 85 per cent lime phosphate.

Hayes has advanced the theory that the lime phosphate of the white phosphates was originally extracted from sea water by organisms, and accumulated on the bottom either as nodules or disseminated through the sediments. Later, when these strata were lifted above sea level and subjected to erosion and the action of percolating waters charged with acids from the soil, the phosphate was leached out and carried to lower levels where it was redeposited either in cavities or by replacing limestone.

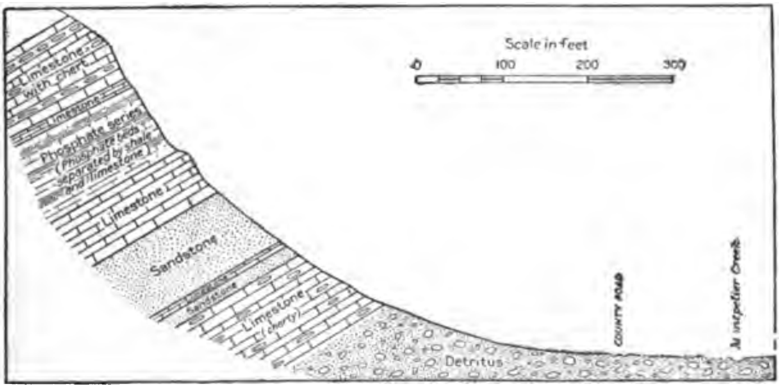

FIG. 76. — Section of Carboniferous strata on north side of Montpelier Creek, Ida. (*After Weeks and Ferrier, U. S. Geol. Surv., Bull.* 315, 1906.)

At the present time the brown rock phosphate is the most important commercially.

Wyoming-Idaho-Utah (25, 26). — Large areas of phosphate rock have been discovered in the western states (Fig. 75), within the last few years. The deposits, which are said to be the most extensive thus far discovered in the world, will no doubt prove to be of great importance in the future, although at present their development has been retarded, partly by lack of transportation facilities and limited demand.

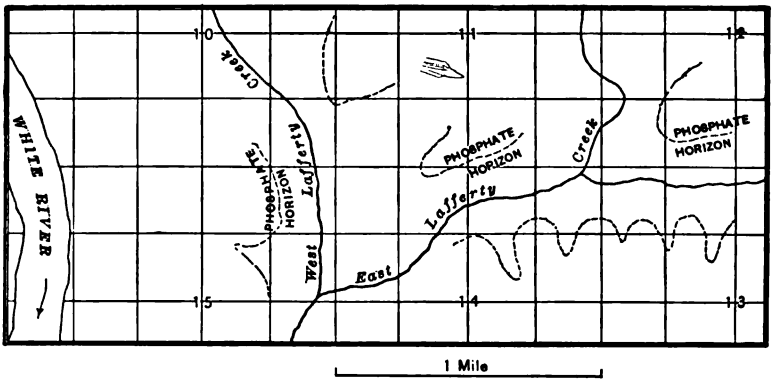

Fig. 77. — Map of portion of Lafferty Creek, Ark., phosphate district, showing position of phosphate outcrops. (*After Branner and Newsom, Ark. Agric. Exp. Sta., Bull.* 74.)

The phosphate is found in rocks of Upper Carboniferous age, interstratified with shales and sandstones, the average section being as shown in Fig. 76. The beds strike northwest and southeast, or parallel with the trend of the ranges in which they outcrop, and show a variable dip, because of the folding and faulting that has disturbed them. At the base of the section is a limestone, which is separated by a thin shale from the main or overlying phosphate bed. This latter is 5 to 6 feet thick, and of

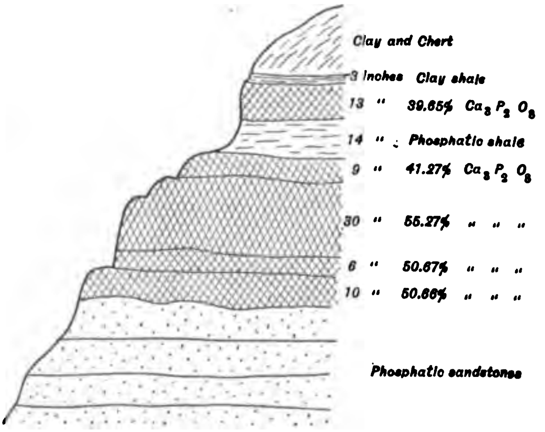

Fig. 78. — Section in Lafferty Creek, Ark., Phosphate district. (*After Branner and Newsom, Ark. Agric. Exp. Sta., Bull.* 74.)

oölitic character, but the range of thickness is a few inches to 10 feet. The lime phosphate content in the workable beds varies from 65 to 80 per cent, with an average of 72 per cent.

A knowledge of the stratigraphy in this region is of importance, because of the similarity of the stratified Cambrian, Ordovician, and Silurian sediments to some of the Carboniferous ones. Some phosphate has been shipped from Montpelier, Idaho, and used in superphosphate manufacture at Martinez, California.

Arkansas (9, 10, 21). — Phosphate deposits have been developed on Lafferty Creek, on the western edge of Independence County, but the beds extend from about 10 miles northeast of Batesville, to St. Joe in Searcy County, a distance of about 80 miles. The phosphate which forms a bed 2 to 6 feet thick in the Cason shale of the Ordovician is light gray, homogeneous and conglomeratic with small pebbles. It carries from 25 to 73 per cent lime phosphate. The following section is shown on Lafferty Creek (Fig. 78).

	FEET	INCHES
St. Clair limestone	—	—
Brown to black shale	2	0
Low-grade manganese iron ore	1	3
Green to dark gray shale	1	2
High-grade phosphate	4½–6	—
Manganese-iron ore	—	2
Low-grade phosphate	4	—
Polk Bayou limestone	—	—

The Arkansas phosphates were discovered in 1895, but were not developed until 1900. The field will be of doubtful importance until low and medium-grade rock is marketable.

The true nature of these phosphate deposits does not appear to have been recognized for some years.

Branner and Newsom consider them to be deep-sea (though not abysmal) deposits, formed from the droppings of fishes and other marine animals, and to accumulations of organic matter that settled to the bottom of the quiet waters.

Purdue believed the beds to have been laid down near shore as the sea advanced landward, and the phosphatic nature as due mainly to fragments of organic matter, but may have been in part the droppings of marine animals. The conglomerate character is thought by him to confirm the shallow-water theory.

Other Phosphate Occurrences. — Phosphate, in the form of nodules, white vesicular rock, and in limestone fragments, occurs along the contact of Oriskany (Devonian) sandstone and Lower Helderberg (Silurian) limestone, in Juniata County, Pennsylvania (17). It contains 30 to 54 per cent bone phosphate. Nodular phosphate, although not worked for fertilizer, is known to occur in Cretaceous and Tertiary strata in Alabama (24), Georgia (19), North Carolina (11), and Virginia (25 *a*).

Analyses of Phosphates. — The following analyses will serve to show the composition of some native phosphates. Of the impurities present, lime carbonate is undesirable, since it neutralizes the acid used in phosphate manufacture. Iron oxide, alumina, and silica are inert impurities displacing just so much phosphate of lime.

The richness of a phosphate is usually expressed in terms of the tribasic-calcic phosphate, commonly termed bone phosphate. Of this about 45.80 per cent is phosphoric acid.

ANALYSES OF PHOSPHATE ROCK

	MOISTURE	P_2O_5	Fe_2O_3	Al_2O_3	CO_2	$CaCO_3$	INSOL.	H_2O, ORG.	CaO	Fe + UNDET.	BONE PHOSPHATE	MISCEL.
TENNESSEE												
Mt. Pleasant	1.05	34.69	2.39	3.36	1.40	3.18	4.05	2.64	46.76	1.39	76.42	
Swan Creek, Hickman Co.	.50	28.27	3.14	2.93	1.15		13.24		40.50			2.80
White phosphate, Stone Quarry Hollow, Perry Co. . . .		15.30				8.23	54.88		22.76			
FLORIDA												
Hard rock .	.07	38.84	.96	3.07	.65		.49	2.96	50.08	2.46		MgO .30
Washed land pebble . .	.63	34.72	1.35	2.53	2.19		4.34	2.72	47.95	3.15		.21
River pebble	.56	28.33	1.05	2.01	3.99		12.23	4.90	42.75	2.44		.44
SOUTH CAROLINA												
Average, S. C. Analysis .	3.68	25.61			4.68		11.55	4.78			55.91	

Guano (31, 32). — Under this name are included surface deposits of excrement, chiefly of birds. Penrose (25) recognizes two classes: (1) soluble guano, of recent origin, which still contains most of its soluble ingredients; (2) leached guano, which has lost its soluble constituents by the action of rain or sea water. Most of the soluble guano of commerce was formerly obtained from Peru, where, it is said, the Incas, as well as the early Spaniards, valued it so highly that a death penalty was imposed for killing the birds which produced it. These deposits, from which many thousand tons have been obtained, are now exhausted. No large deposits of bird guano are known in the United States. Leached guanos occur on islands in the southern Pacific and in the West Indies.

Bat guano has been found in the caves of Kentucky, Texas (32), and many other states, but few of the deposits have proved large enough to work, and none are of great extent, although one cave in Texas was known to yield 1000 tons. The following analysis is representative: ammonia, 9.44 per cent; available phosphoric acid, 3.17 per cent; potash, 1.32 per cent.

Greensand. — This term is applied to beds of marine origin, made up in large part of the green sandy grains of glauconite, the hydrated silicate of iron and potash. It also contains small amounts of phosphoric acid. Green sands (29) are found at many localities in the Cretaceous and Tertiary formations of the Atlantic Coastal Plain, but New Jersey (28) and Virginia are the two important producers. The New Jersey greensand is spread on the soil in its raw condition, but that from Virginia is dried and ground for use in commercial fertilizers.

The following analyses show its variable composition, and the comparatively small amount of P_2O_5 and K_2O necessary to make it of value as a fertilizer.

ANALYSES OF GREENSAND

	P_2O_5	SO_3	SiO_2	CO_2	K_2O	Na_2O	CaO	MgO	Al_2O_3	Fe_2O_3	H_2O
Pemberton, N. J.	1.02	.27	50.23	—	6.32	1.59	1.40	3.45	7.94	20.14	9.00
Aquia Creek, Va.	.09	—	21.58	29.79	.37	.59	36.78	1.05	7.70	—	.76

Uses. — Fertilizers are used either in their raw condition or after undergoing preparation. Lime carbonate is commonly calcined before being spread on the soil, while gypsum is first pulverized before being sold as land plaster.

Phosphate rock is treated with sulphuric acid to produce superphosphate or acid phosphate, and in this treatment ammoniates, or potash, or both, are sometimes added to the material. Concentrated phosphate is made by treating the phosphate rock with enough sulphuric acid to entirely decompose it, converting all the lime into sulphate, the phosphoric acid solution being drawn off and further treated with additional quantities of high-grade phosphate. Since this form of phosphate therefore requires raw materials of a high grade, and is much more extensively manufactured in Europe than in the United States, most of the high-grade Florida rock is exported.

Production of Fertilizers. — The production of phosphate in the United States for several years was as follows: —

PRODUCTION OF PHOSPHATES IN THE UNITED STATES, 1904 TO 1908

	1904		1905			1906			1907			1908		
	LONG TONS	VALUE	LONG TONS	VALUE	AVER. PRICE PER TON	LONG TONS	VALUE	AVER. PRICE PER TON	LONG TONS	VALUE	AVER. PRICE PER TON	LONG TONS	VALUE	AVER. PRICE PER TON
Florida:														
Hard rock . . .	531,087	$2,672,184	577,672	$2,993,732	$5.18	587,598	$3,440,276	$5.85	646,156	$4,065,375	$6.29	595,743	$4,566,018	$7.66
Land pebble . .	460,834	1,102,993	528,587	1,045,113	1.98	675,444	2,029,202	3.00	675,024	2,376,261	3.52	1,085,199	3,885,041	3.58
River pebble . .	81,030	199,127	87,847	213,000	2.42	41,463	116,100	2.80	36,185	136,121	3.76	11,160	33,480	3.00
Total . . .	1,072,951	3,974,304	1,194,106	4,251,845	3.56	1,304,505	5,585,578	4.28	1,357,365	6,577,757	4.85	1,692,102	8,484,539	5.01
South Carolina:														
Land rock . . .	258,806	830,117	234,676	774,447	3.30	190,180	711,447	3.74	228,354	883,965	3.87	192,263	854,837	4.45
River rock . .	12,000	31,200	35,549	103,722	2.92	33,495	105,621	3.15	28,867	96,902	3.36	33,232	135,044	4.06
Total . . .	270,806	861,317	270,225	878,169	3.25	223,675	817,068	3.65	257,221	980,867	3.81	225,495	989,881	4.39
Tennessee:														
Brown rock . .	—	—	438,139	1,509,748	3.45	510,705	2,027,917	3.97	594,594	2,880,904	4.85	374,114	1,572,525	4.20
Blue rock . . .	—	—	44,031	121,486	2.76	35,669	114,997	3.22	38,993	142,382	3.65	79,717	299,941	3.76
White rock . .	—	—	689	2,155	3.13	1,303	5,077	3.90	5,025	24,550	4.89	1,600	4,755	2.97
Total . . .	530,571	1,745,054	482,859	1,633,389	3.38	547,677	2,147,991	3.92	638,612	3,047,836	4.77	455,431	1,877,221	4.12
Other states . . .	—	—	—	—		[1] 5,100	28,800	5.65	[2] 12,145	47,098	3.88	[2] 13,110	47,483	3.62
Grand total . .	—	—	1,947,190	6,763,403	3.47	2,080,957	8,579,437	4.12	2,265,343	10,653,558	4.70	2,386,138	11,399,124	4.78

[1] Includes Arkansas and Idaho.

[2] Includes Idaho, Arkansas, Utah, and Wyoming.

Exports and Imports. — The following table shows what a large percentage of the phosphate rock produced in the United States is exported.

PRODUCTION AND EXPORTATION OF PHOSPHATE ROCK IN THE UNITED STATES, 1904 TO 1908, IN LONG TONS

YEAR	PRODUCTION	EXPORTATION	YEAR	PRODUCTION	EXPORTATION
1904	1,874,428	842,484	1907	2,265,343	1,018,212
1905	1,947,190	934,940	1908	2,386,138	1,188,411
1906	2,080,957	904,214			

These exports are sent to all parts of Europe, Germany being the largest consumer. The imports since 1904 have been as follows: —

FERTILIZERS IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES, 1904–1908, IN LONG TONS

YEAR	GUANO		KIESERITE AND KAINITE		APATITE, BONE DUST, CRUDE PHOSPHATES, AND OTHER SUBSTANCES USED ONLY FOR MANURE		TOTAL VALUE
	Quantity	Value	Quantity	Value	Quantity	Value	
1904 . .	37,127	$498,702	218,957	$1,050,082	243,130	$2,455,618	$4,004,402
1905 . .	27,104	379,667	351,053	1,850,622	197,115	2,450,835	4,681,124
1906 . .	23,222	322,766	334,843	1,790,969	211,274	2,598,451	4,712,186
1907 . .	30,287	400,054	346,266	2,526,584	194,121	2,579,843	5,506,481
1908 . .	5,728	92,659	129,063	730,934	96,091	1,153,002	1,976,595

World's production. — The table given below is of interest since it brings out clearly the leading position of the United States as a producer of phosphates.

WORLD'S PRODUCTION OF PHOSPHATE ROCK, 1905–1907, BY COUNTRIES, IN METRIC TONS

COUNTRY	1905		1906		1907	
	Quantity	Value	Quantity	Value	Quantity	Value
Algeria	334,784	$1,225,126	333,531	$965,600	373,763	$2,142,352
Aruba (Dutch West Indies)	23,307	42,188	26,138	[1]	[2]	—
Belgium	193,305	332,292	152,140	282,612	[2]	—
Canada	1,338	8,876	521	4,024	748	6,018
Christmas Island (Straits Settlements)	99,519	[1]	92,010	[1]	[2]	—
France	476,720	2,093,118	469,408	1,872,000	431,237	1,876,736
Norway	2,522	33,768	3,482	46,524	[2]	—
Spain	1,370	7,295	1,300	7,592	—	—
Tunis	521,731	1,812,493	796,000	2,304,400	1,069,000	[1]
United Kingdom . .	—	—	—	—	43	224
United States . . .	1,978,345	6,763,403	2,114,252	8,579,437	2,301,588	10,653,558

[1] Value not reported.

[2] Statistics not yet available.

REFERENCES ON FERTILIZERS

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CHAPTER IX

ABRASIVES

Introductory. — Under this heading are included those natural products which are employed for abrasive purposes. Since the main use of some is not for work of abrasion, they are simply referred to briefly in this chapter, the detailed description of them being given on another page. Brief reference will also be made to some artificial compounds which come into serious competition with the natural ones.

While some abrasive substances occur as constituents of veins, or in disseminated form, the great majority form a part of rocks of either sedimentary, igneous, or metamorphic origin, and of various degrees of consolidation. That they are widely distributed both geologically and geographically is shown in the following description of the individual groups, and the map (Fig. 79): —

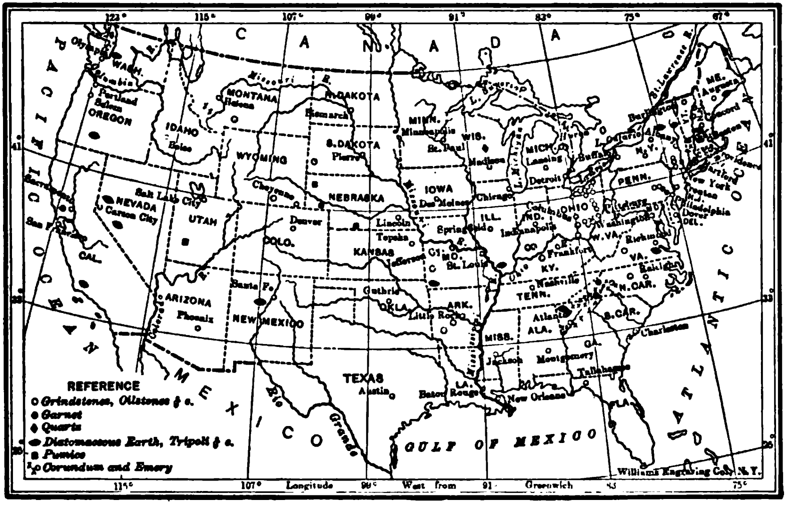

Fig. 79. — Map showing distribution of abrasives in United States.

Millstones and Buhrstones[1] (2) are stones of large diameter used for grinding cereals, paint ores, cement rock, barite, fertilizers, etc. The American stones are either coarse sandstone or quartz conglomerate, and are quarried at several points along the eastern side of the Appalachian Mountains from New York to North Carolina. The most important beds are in the Shawangunk Grit, which is quarried in the Shawangunk Mountains of eastern New York (20, 21). Some are also quarried in Pennsylvania, North Carolina, and Virginia (22). The material adapted to millstones is very limited in extent. Some of the stone is also cut into chasers, used for grinding quartz and feldspar. Owing to the use of improved grinding machinery the demand for millstones has fallen off greatly in recent years.

Many buhrstones are imported from France, Belgium, and Germany. Those from the first two localities are hard, cellular rocks, consisting of a mixture of fine quartz particles and calcareous material; but the German buhrstone is basaltic lava.

Grindstones (2, 13). — These are made from sandstones of homogeneous texture and sufficient cementing material to hold the quartz grains together, but not enough to so fill the pores as to make the rock wear smooth under use. Most of the grindstones produced in the United States are obtained from the Berea grit of Ohio (Pl. XXIV, Fig. 1) and Michigan, certain layers of which are highly prized for this purpose. West Virginia, Montana, and Missouri also contribute to the output.

Pulpstones, which have a diameter of 48 to 56 inches, a thickness of 16 to 26 inches, and a weight of 2300 to 4800 pounds, are a thicker variety of grindstone. They are used for grinding wood pulp in paper manufacture, and hence have to withstand continual exposure to hot water. On account of their superior quality, pulpstones from Newcastle-upon-Tyne, England, supply most of the American demand; but it is probable that certain beds of the Ohio sandstones will be found suited for this purpose (2).

Whetstones, Oilstones (2, 13, 17), etc. — The term "whetstone" includes those stones used for sharpening tools, the term "oilstone" being often applied when oil is placed on the stone to prevent heating and clogging of the pores by grains of steel. The stones used for making whetstones are either sedimentary or metamorphic in character, and include sandstone, quartzite, mica schist, and novac-

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[1] The term buhrstone belongs properly to those millstones made of a chalcedonic cellular rock, full of cavities, some of them representing casts of shells.

PLATE XXIV

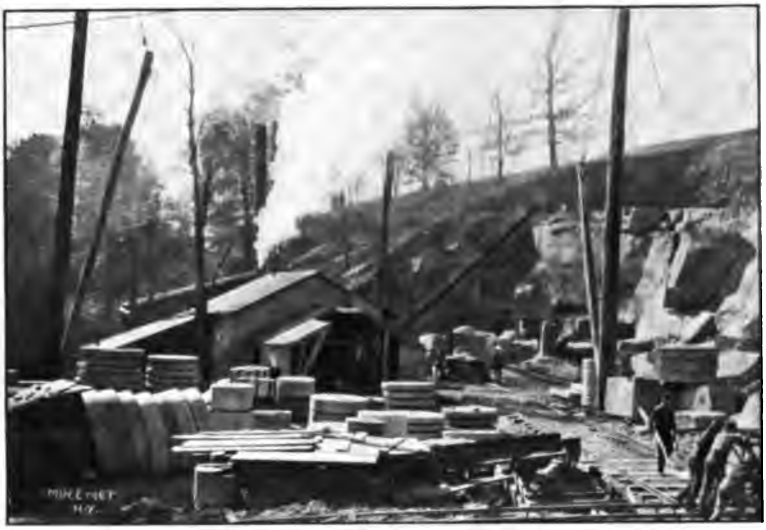

FIG. 1. — Grindstone quarry, Tippecanoe, Ohio. (*J. H. Pratt, photo.*)

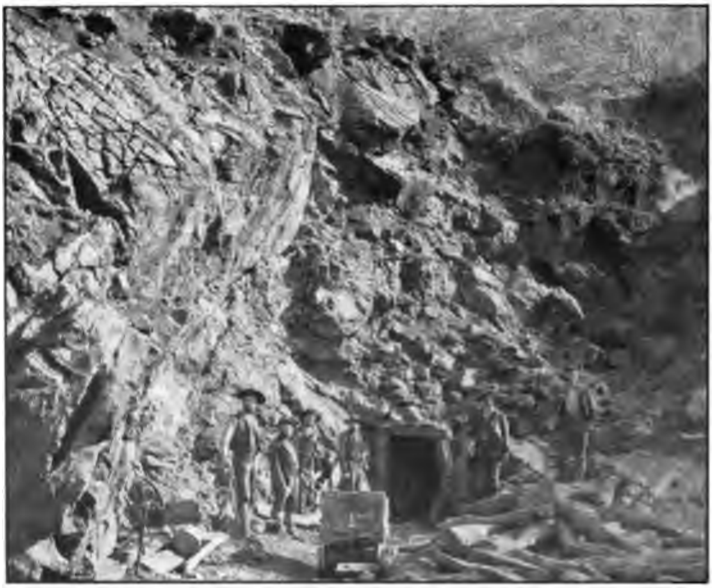

FIG. 2. — Corundum vein between peridotite and gneiss, Corundum Hill, Ga. (*After Pratt, U. S. Geol. Surv., Bull.* 180.)

ulite. The stone selected will naturally vary somewhat with the exact use to which it is to be put, but even texture and comparatively fine grain are essentials. A small amount of clayey matter adds to the fineness of grinding, but an excess lowers the abrasive efficiency of the stone. In the schists used, abrasive action is due to the grains of quartz, or sometimes garnet, which are embedded among the fine-grained scales of mica.

Rocks suitable for whetstone manufacture are found in many states, especially east of the Mississippi (2, 13), but, on account of keen competition and limited demand, only the better grades from the best-located deposits are employed. Most of the supply is therefore obtained from a few states, especially Arkansas, Indiana, Ohio, New York, Vermont, and New Hampshire.

Among the whetstones quarried in the United States, the Hindostan or Orange stone of Indiana and the Deerlick oilstone of Ohio are much used for oilstones. Scythestones are made from schistose rock in Grafton County, New Hampshire, and Orleans County, Vermont.

At Pike Station, N. H. (Pl. XXII, Fig. 2), the raw material quarried for scythestones is a fine-grained, thinly laminated, micaceous sandstone, whose quartz grains occur in definite layers, separated by thin layers of mica flakes. Those portions of the rock in which the quartz grains are coarse or irregularly disposed, as well as argillaceous portions, are unfit for abrasive purposes.[1]

The novaculite quarried in Garland and Saline counties, Arkansas (17), represents a unique type, much prized for high-grade oilstones for sharpening small tools, and in demand both at home and abroad. It is an extremely fine grained sandstone made up of finely fragmental quartz grains, visible under the microscope. The rock is chertlike in superficial appearance and has a conchoidal fracture. While the deposits, which are stratified, have a total thickness of over 500 feet, the commercial novaculite is found only in thin beds varying from a few inches to 15 feet in thickness. The

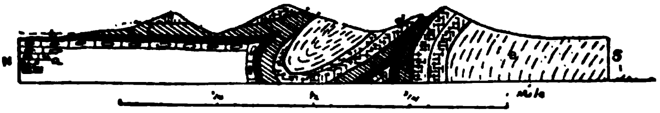

FIG. 80. North-south section through Missouri and Statehouse Mountains showing folded character of novaculite and slate-bearing formations of Arkansas. *a.* Bigfork chert; *b.* Polk Creek shale; *c.* Missouri Mountain slate; *d.* Arkansas novaculite; *e.* Stanley shale. (*After Purdue, Ark. Geol. Surv.*, 1909.)

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[1] Min. Res., U. S. Geol. Surv., 1908.

beds have a steep dip (Pl. XXV and Fig. 80), and are cut by several series of joints, which greatly interfere with the extraction of large blocks, and sometimes even with small ones. There are also structural irregularities and almost invisible flaws, so that much waste is caused in quarrying the rock. The rock has been variously regarded as a metamorphosed chert, a siliceous silt, or a silicified limestone.

Pumice and Volcanic Ash. — The term "pumice," as used in the geological sense, refers to the light spongy pieces of lava, whose peculiar texture is due to the rapid and violent escape of steam from the molten lava. It is put on the market either in lump form, or ground to powder, or in compressed cakes of the ground-up material. In the commercial sense the term "pumice" includes volcanic ash (Fig. 81) as well as true pumice.

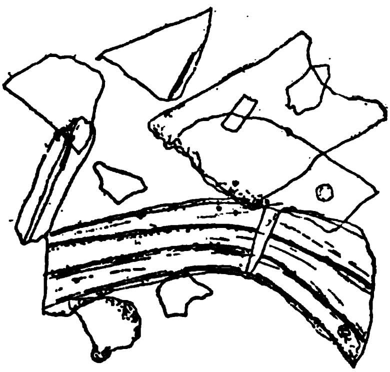

FIG. 81. — Volcanic ash from Madison County, Mont. (*After J. P. Rowe.*)

Most of the pumice used in the United States is obtained from the island of Lipari, north of Sicily. The stone, after being freed from the volcanic ash with which it is mixed, is sorted according to color, weight, and size, before it is shipped to market.

Deposits of volcanic ash are abundant in many western states, for example, in Nebraska (10), Utah (13), Montana (14), Oregon (12), Wyoming (11), Colorado (15), etc., but owing to their inaccessibility these materials cannot compete with Lipari pumice, which is imported as ballast, and sells in its prepared form for 2 to 2½ cents per pound. The pumice produced in the United States comes from Harlan and Lincoln counties in Nebraska. The deposits must be very abundant in this state, as Barbour remarks that nearly the whole of it is overlain by pumice beds as far east as Omaha.

Diatomaceous Earth.[1] — This material has been used to some extent for abrasive purposes, either in the form of polishing powder or in scouring soap. Since it has many other and more important possible applications, it is described separately on a later page.

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[1] Infusorial earth and Tripoli are terms sometimes applied to Diatomaceous earth. Both are incorrect.

Plate XXV. — View in Arkansas novaculite quarry. (*Photo. loaned by Pike Manufacturing Co.*)

Tripoli. (See p. 290.) — Some of the Missouri tripoli is ground and sold as tripoli flour, whose value f.o.b. is $6–$7 per ton. This flour is employed as an abrasive for general polishing, burnishing, and buffing, as well as an ingredient of scouring soaps.

The so-called "silica" obtained in Union County, Illinois, is similar to tripoli, and may have had the same origin.

Crystalline Quartz (2, 13). — Some of the vein quartz quarried in the United States, and also quartzite, is pulverized and used for abrasive purposes. Considerable quartz sand is employed by stone cutters as an abrasive in sawing stone, and a small quantity is utilized in making sandpaper. (See further, p. 274.)

Feldspar (13). — This also is used to a small extent for abrasive purposes, but since it has other and more important uses it is discussed separately on p. 225.

Garnet (13, 16). — The garnet group includes several mineral species which are essentially silicates of alumina with iron or lime, magnesia, manganese, and chromium. They crystallize in the isometric system, have a hardness of 6.5 to 7.5 and a specific gravity of 3.55 to 4.30. Their color is variable, but commonly a shade of red or brown. The two commonest species are *Almandite* [$Fe_3Al_2(SiO_4)_3$] and *Grossularite* [$Ca_3Al_2(SiO_4)_3$].

Garnet is a common mineral in many metamorphic rocks, and though ordinarily a subordinate constituent of these, it may in some cases become the chief one. Its hardness, together with its ready cleavage and splintery fracture, make it a most valuable abrasive for certain lines of work.

Though widely distributed, deposits of economic value are comparatively scarce.

New York (16). — The garnet industry is an important one in the Adirondack region of New York, a steady production coming from Essex and Warren counties. The garnet is commonly associated with an amphibolite which forms bands and lenses in the more acid country gneiss, and crystals ranging from an inch or less up to several feet in diameter are found. The garnet rock may represent a metamorphosed limestone. Other deposits have been exploited near Keeseville, etc.

Garnet deposits are known to occur in North Carolina, and have been worked from time to time, especially in Madison County. A little has also been produced in New Hampshire.

Uses. — Garnet is used in the manufacture of garnet paper, being a valuable abrasive for leather and wood. It has also been employed in polishing and grinding brass. Attempts have been made to use it as a substitute for corundum in the manufacture of emery wheels, for, although softer, it possesses the advantage of having a splintery fracture, which prevents it from wearing smooth.

Corundum and Emery (3–9). — *Corundum* (Al_2O_3) is, next to diamond, the hardest of the natural abrasives known, having a hardness of 9, but varying slightly from this.

Its fracture is irregular to conchoidal, and gives a good cutting surface, but the presence of parting planes decreases its value. A specific gravity of 4 helps to distinguish it from other light-colored minerals found in the corundum regions. Corundum shows a variable behavior when heated, some forms crumbling when exposed to a high temperature. Such kinds are worthless for the manufacture of emery wheels, all of which must be fired in order to fuse the clay bond used in their manufacture.

Nearly all corundum analyses show SiO_2, Fe_2O_3, and H_2O, and it must be remembered that in analyses of commercial corundum the alumina percentage does not indicate the quantity of corundum present, as some of it may belong to other aluminous silicates.

The following analyses represent selected rather than commercial samples: —

ANALYSES OF CORUNDUM

	Al_2O_3	Fe_2O_3	SiO_2	H_2O	INS. RES.	TOTAL
Hastings Co., Ont.	96.92			2.43	1.36	100.71
Corundum Hill, N. Ca. . . .	98.79	.75	.90	.78	—	101.22
Laurel Creek Mine, Ga. . . .	95.51	.88	1.45	.74	—	98.58
Ruby from India	97.32	1.09	1.21	—	—	99.62
Sapphire from India	97.51	1.89	.80	—	—	100.20

Corundum may occur in masses, crystals, or irregular grains. It is found in both igneous and metamorphic rocks, as well as in alluvial deposits derived from them, although the last supply but little abrasive corundum.

Corundum forms a primary constituent (sometimes an important one) of feldspathic igneous rocks, both high and low in silica. It is found in granite, syenite, nephelite-syenite, and coarse pegmatites. It is also known to occur in crystalline schists and metamorphosed limestones.

A number of other minerals may be associated with it as follows (5):

Associated minerals.

In gneiss and granite: Besides essentials, garnet magnetite, pyrite zircon, rarely monazite and sodalite.

In peridotites and basics: Olivine, magnesian amphibole, pyroxenes, rarely plagioclase, while chromite and spinel are accessory primaries.

In contact zones: corundum, biotite, muscovite, garnet, staurolite, tourmaline, rutile, etc.

In regionally metamorphosed rocks: biotite, muscovite, amphibole, sillimanite, cyanite.

Distribution. — With the exception of a few localities in Montana, two in Colorado, one in Idaho, and one or two in California, all the known United States occurrences are confined to the Appalachian region, the commercially valuable deposits for abrasive purposes being found in a belt of basic magnesian rocks, extending from Massachusetts to Alabama. These rocks reach their greatest development in North Carolina (5) and Georgia (3). Most of the corundum is found there, in peridotite, especially near its contact with the surrounding gneiss.

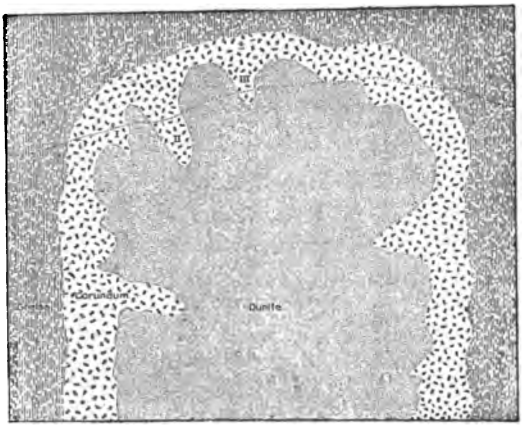

FIG. 82. — Section showing occurrence of corundum around border of dunite mass. (*After Pratt, U. S. Geol. Surv., Bull.* 180.)

It is believed that the corundum which was one of the earliest minerals to crystallize out from the cooling peridotite was concentrated around the borders of the mass by convection currents. This zone of corundum sent off tongues toward the interior of the mass, and now that erosion has removed the main zone of corundum, these tongues remain as apparently separate veins within the peridotite (Fig. 82).

In North Carolina (5) the greatest development of corundum is in a belt in Macon County. Some is also found east of the Blue Ridge. Georgia (3) contains scattered deposits, the most important being at Pine Mountain, Rabun County. Some mining has been done in South Carolina and Georgia, and deposits in garnetiferous mica schists cut by granite have been recorded from Patrick County, Virginia (9).

Emery. — This is a mechanical mixture of corundum, magnetite or hematite, and sometimes spinel. Peekskill, New York (6–8), and Chester, Massachusetts, are the most important sources of production.

At the former locality, the deposits which lie southeast of the town, and were first opened for iron ore, occur along the contact of basic intrusions belonging to the gabbro series. The emery deposits, according to G. H. Williams, are simply segregations of the basic oxides in the norite, and the ore is made up of corundum, magnetite, and hercynite (an iron-aluminum-spinel). In some specimens the corundum forms over 50 per cent of the mass, while in others the hercynite may make up nearly 100 per cent of it. The Peekskill material is very serviceable when made into wheels with a bond. The following are analyses of it.

	I	II	III
Al_2O_3	20.95	38.78	46.53
SiO_2	13.97	—	—
TiO_2	4.15	.62	.51
Fe	40.32	—	—
Fe_2O_3	—	24.35	32.31
MgO	—	7.92	9.43
P_2O_5	—	tr.	tr.
Si residue	—	11.19	2.42
Fe_3O_4	—	17.37	8.98
S	—	.02	.01

I. Am. Chemist, 1874, 4: 321. II and III. A. J. S., March, 1887, p. 197.

At Chester, Massachusetts (13), the emery occurs in a local widening of a belt of amphibolite schists, and forms a vein traceable for nearly five miles. The emery-bearing vein varies in width from a few feet up to 10 or 12 feet, while the emery streak in it averages about 6 feet, it being bordered on both sides by chlorite seams. The emery is in pockets, but these are traceable by a small vein of chlorite.

After mining, both corundum and emery need to be cleaned and concentrated by special mechanical processes. The chief use of this material is as an abrasive, and for this purpose it is used in the form of wheels and blocks, emery paper, and powder.

Practically all the corundum and emery used in the United States is imported. The emery is imported crude as ballast from Turkey and Greece. Corundum is imported mainly from Canada in pulverized form.

Diamonds. — Black diamonds, known as *borts* and *carbonados*, which are of no value for gem purposes, are much sought after for use in drilling, being set in the end of the cylindrical drill tube. They are often of rounded form, translucent to opaque, and lack the cleavage possessed by the gem diamonds. Brazil, Africa, Borneo and India serve as sources of supply, but the first-named country is said to yield the best ones. The ordinary sizes for drills weigh from ½ to 1 carat, but in special cases pieces weighing 4 to 6 carats are used. The price ranges from $50 to $75 per carat.

Diamond powder is also used as an abrasive for cutting other diamonds, gems, glass, and hard materials which cannot be cut by softer and cheaper substances.

Artificial Abrasives. — Several artificial abrasives are now much manufactured. Prominent among these is carborundum, which is produced by fusion in the electric furnace of a mixture of silica, coke, and sawdust; the reaction being $SiO_2 + 3\,C = CSi + 2\,CO$. The sawdust is added to give porosity to the mixture.

Artificial corundum or alundum, whose introduction is of more recent date, is made by fusing bauxite in the electric furnace. It is put on the market in the form of wheels, while carborundum is either made into wheels or sold in powdered form.

Production of Abrasives. — The value of the abrasives produced in the United States during the last five years, together with the imports and artificial abrasives, was as follows: —

VALUE OF ALL ABRASIVE MATERIALS CONSUMED IN THE UNITED STATES, 1904 TO 1908

KIND OF ABRASIVE	1904	1905	1906	1907	1908
Oilstones and scythestones . . .	$188,985	$244,546	$268,070	$264,188	$217,284
Grindstones and pulpstones . .	881,527	777,606	744,894	896,022	536,095
Buhrstones and millstones . . .	37,338	37,974	48,590	31,741	31,420
Pumice	5,421	5,540	16,750	33,818	39,287
Diatomaceous earth and tripoli .	44,164	64,637	72,108	104,406	97,442
Abrasive feldspar and quartz . .	74,850	88,118	121,671	126,582	79,146
Garnet	117,581	148,095	157,000	211,686	64,620
Corundum and emery	57,235	61,464	44,310	12,294	8,745
Total	$1,407,101	$1,427,980	$1,473,393	$1,680,737	$1,074,039
Artificial abrasive	830,926	701,400	777,081	1,027,246	626,340
Imports	547,804	654,821	909,964	754,140	476,073
Grand Total	$2,785,831	$2,784,001	$3,160,438	$3,462,123	$2,176,452

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CHAPTER X

MINOR MINERALS. ASBESTOS

Asbestos Minerals (1, 13). — Two different minerals are mined and sold under this name, one a variety of amphibole, the other a fibrous variety of serpentine, known as chrysotile.

The amphibole asbestos forms pockets or masses (mass fiber) or veins in gneissic or schistose rocks, and is of a white, gray, or greenish-white color. The veins may carry either *slip fiber*, whose threads lie parallel to the vein walls, or *cross fiber*, which extends across the vein. The following is an analysis of that found in Elzevir township, Hastings County, Ontario, Canada (1); SiO_2, 61.82; MgO, 23.98; FeO, 6.55; CaO, 1.63; Al_2O_3, 1.12; H_2O, 5.45.

The chrysotile ($H_4Mg_3Si_2O_9$) usually occurs as cross fiber, more rarely slip fiber, in veins of varying width in serpentine rock, its color being greenish white, green, or yellow, and its luster silky. Its hardness is 3 to 3.5 and its specific gravity 2.2 to 2.3. The following analyses are given by Cirkel (1).

	I	II	III
SiO_2	40.30	39.05	40.87
MgO	43.37	40.07	41.50
FeO	.87	2.41	2.81
Al_2O_3	2.27	3.67	.90
H_2O	13.72	14.48	13.55
	100.53	99.68	99.63

I. Italian fiber. II. Chrysotile, Thetford, Quebec. III. Chrysotile, Broughton, Quebec.

The difference in composition between the amphibole and chrysotile are quite noticeable.

In both forms of asbestos the fibers are easily separated, but the amphibole variety often contains gritty impurities which are difficult to remove. The fibers of chrysotile are shorter than those of the amphibole asbestos, rarely exceeding 2½ inches in length, but they have greater strength and are less brittle. Since the amphibole asbestos can be mined more easily, it is cheaper than the chryssotile variety, which, nevertheless, is in greater demand because more constant in character and suited to more uses. The two varieties are equal in value as non-conductors of heat.

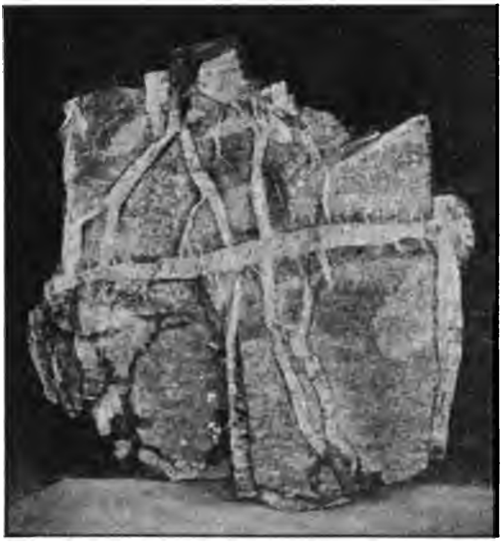

FIG. 83. — Asbestos vein in serpentine. (*Photo. by G. P. Merrill.*)

Distribution in United States. — The ancient crystalline rocks in which the famous Quebec deposits occur, extend southwestward through the eastern states, as far as Alabama, and while a number of small deposits of asbestos are known, yet nowhere are there any large ones, moreover, most of the deposits are of the amphibole type.

Vermont (8, 9). — The only chrysotile deposit worked in the eastern belt is in Lamoille and Orleans counties, Vermont, where the material is found occupying a rather limited area in a large serpentine area (9). Two types of chrysotile are found, one forming branching veins similar in character and quality to the Canadian fiber, the other, of inferior quality, occurring as short fibers on slickensided surfaces. In 1908 a mill was erected near Lowell, Vermont, for separating the fiber.

Georgia (2). — Salls Mountain, Georgia, has been the main source of supply of asbestos in the United States for over a dozen years, the material being of the amphibole type. The asbestos occurs as masses of fibrous amphibolite (mass fiber) in gneiss, the largest discovered body being about 75 feet long, and about 50 feet wide near the middle. The amphibolite may be an altered eruptive.

The fibers, which range in length from 1¼ inches down to a fraction of an inch, may form over 90 per cent of the original rock. They contain a little talc and lime carbonate as well as numerous small grains of pyrite and magnetite (2). Weathering softens the mass without destroying its fibrous structure, but the strength is somewhat reduced. The material is milled at Salls Mountain.

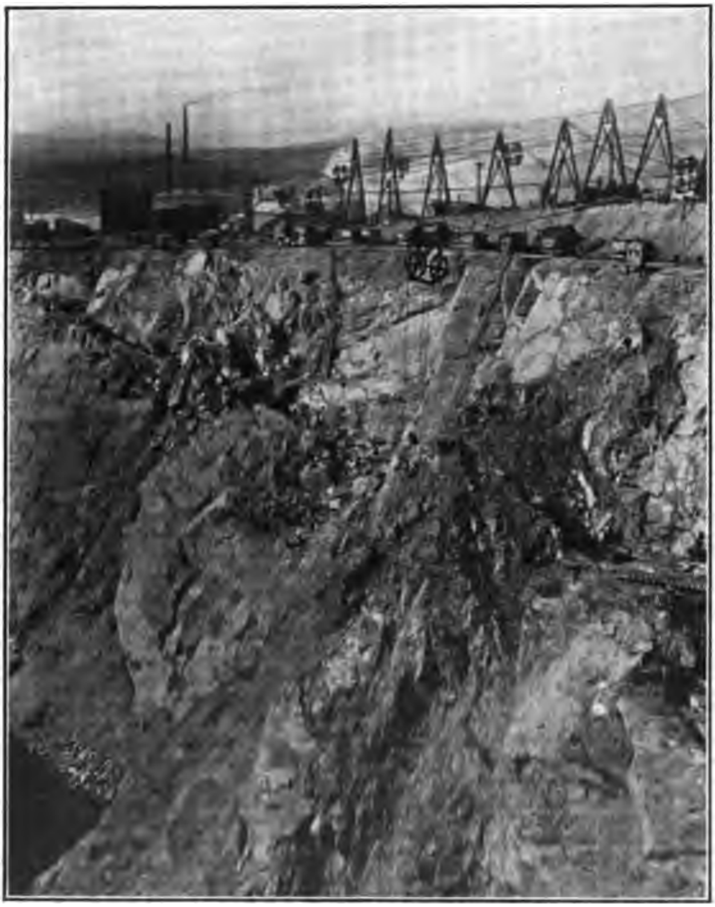

Plate XXVI. — General view of asbestos quarry, Thetford Mines, Que. (*H. Ries, Photo.*)

Virginia (15). — Amphibole asbestos occurs in a number of the Piedmont counties of Virginia, but Bedford has been the main producer. The asbestos is found in more or less well defined veins in granitic or schistose rock, the veins varying from 8 to 50 inches in width.

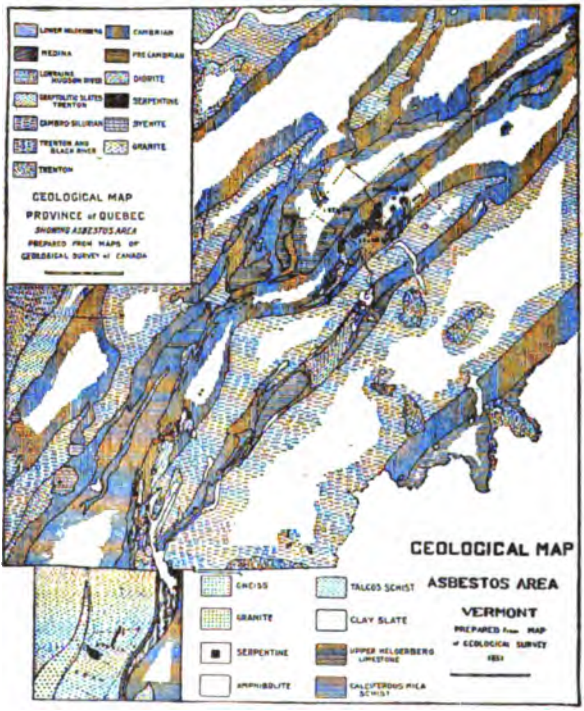

FIG. 84. — Geologic map of Vermont asbestos area. (*After Marsters, Geol. Soc. Amer., Bull. XVI*, 1905.)

ANALYSES OF VIRGINIA, GEORGIA, AND VERMONT ASBESTOS

	I	II	III	IV
SiO_2	56.26	55.81	57.12	39.97
Al_2O_3	1.81	1.66	.75	7.27
FeO	6.40	6.81	6.36	
CaO	11.98	12.74		.50
MgO	20.85	21.09	29.44	40.78
Ign.	2.65	1.81	5.47	12.51
	99.95	99.92	99.14	101.03

I. Albemarle Co., Va. (Ref. 15). II. Roanoke Co., Va. (Ref. 15). III. Salls Mountain, Georgia (Ref. 10). IV. Cross fiber chrysotile, Vermont. (Ref. 9).

Western Occurrences. Chrysotile in serpentine associated with granite has been found in the Casper region, Wyoming (3), and some has been used in Denver for pipe covering, but a more remarkable occurrence is that discovered in the Grand Cañon of the Colorado, 20 miles east of the Grand Cañon station on the Santa Fe Railway (4). Here the asbestos forms veins in serpentine layers and nodules which occur in an Algonkian limestone, which in turn is covered by a diabase. It is suggested that the chrysotile is derived from pyroxene in the limestone. If this is true it forms a unique type of deposit. The locality is at present very inaccessible.

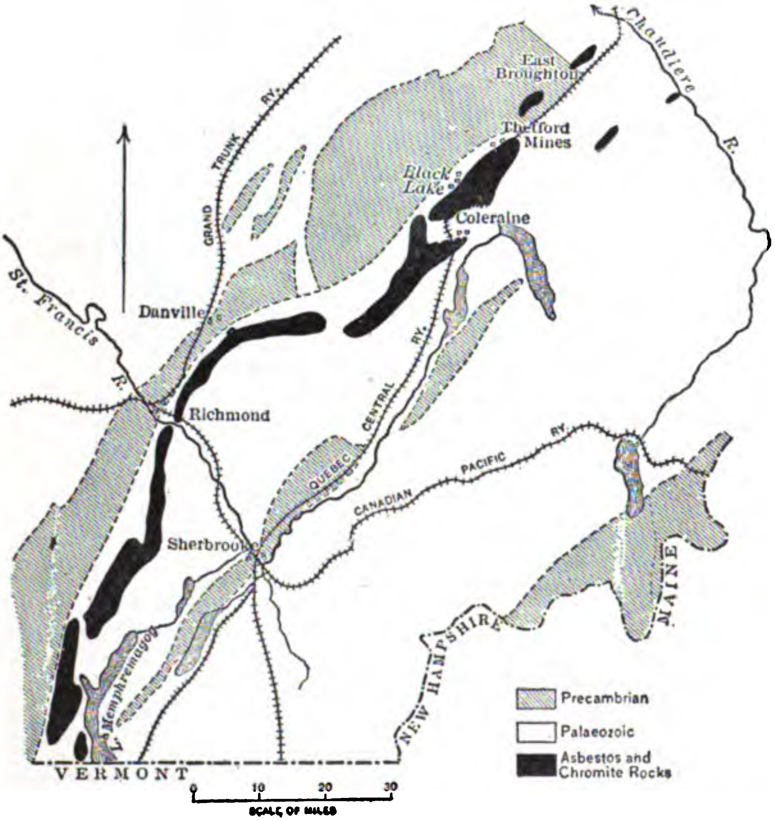

Fig. 85. — Map of Quebec asbestos area. (*After Dresser, Can. Min. Inst., Trans. XII.*)

Quebec, Canada. — The main source of the world's supply is obtained from southern Quebec, and as it is the best known occurrence it may be properly referred to here.

The geologic relations (Fig. 85) of the serpentines and associated rocks are imperfectly known, but it appears certain that they represent an intrusive series, the latest of which cut sedimentary beds of middle Ordovician age. The rocks of the asbestos belt are peridotite, generally much altered to serpentine; pyroxenite, frequently altered to talc; hornblende granite; diabase; and a breccia, in part of volcanic material.

The serpentine is an alteration product of peridotite, it and the pyroxenite being of laccolithic character, while the granite, which forms dikes and isolated masses, may be a final and extremely acid product of differentiation of the general magma of which the basic equivalent is the olivine-rich portion of the peridotite.

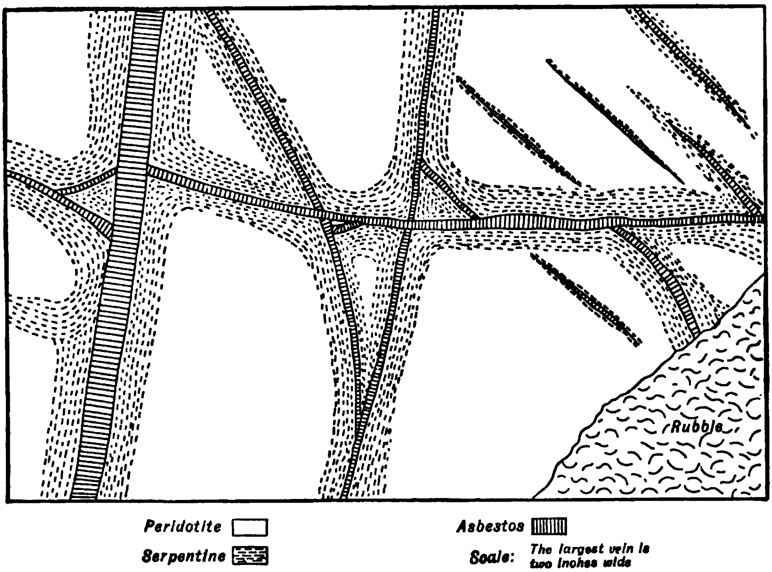

FIG. 86. — Diagram showing asbestos and serpentine in peridotite. (*After Dresser, Econ. Geol., IV.*)

The asbestos is found forming veins in the serpentine, the width of these varying from a mere line to two or three inches. It developed probably first in joint planes, and afterwards in other cracks, forming thus a network (Fig. 86). An interesting and suggestive feature is the band of pure serpentine on either side of the vein (Fig. 86), the ratio of the asbestos vein to the entire band of serpentine and asbestos being 1:6.6. The veins are formed by the growth of minute crystals of chrysotile, perpendicular to the walls, and there is in most cases a central parting marked by a film of chromite or magnetite. The principal mines are near Thetford

Mines (Pl. XXVI), Black Lake, East Broughton, and Danville. The first named locality is of great importance.

The asbestos milling rock forms from 30 to 60 per cent of the quantity quarried, and 6 to 10 per cent of this is fiber.

There has been some difficulty in explaining satisfactorily the origin of the chrysotile veins in serpentine, for we have here two quite different forms of the same mineral. Pratt, in attempting to explain the origin of the vein filling, believes that the fissures represent contraction cracks formed around the edge of the peridotite mass while cooling, and which were then filled by aqueous solutions from which the chrysotile crystallized. Merrill, on the other hand, believes the fissures to have been caused by shrinkage incident to a partial dehydration of the rocks and subsequent filling by crystallization extending from the walls inward (11, 5). As suggested by Kemp, a loss of silica may also have produced some shrinkage.

Cirkel (1), believes the vein crevices to have been formed by partial dehydration, and in part by fracturing resulting from the intrusion of the granite.

All investigators agree on the wall rock being the source of the chrysotile. Dresser (5), while admitting the filling of the veins by infiltration, suggests that they have been enlarged by replacement of the walls. But the serpentinization of the latter precedes the formation of the asbestos.

Uses of Asbestos. — The usefulness of asbestos depends mainly on the flexibility of its fibers, and fibrous structure, and to a less extent on its low conduction of heat and electricity, and on its moderate refractoriness. Asbestos is used in fire-proof paints, boiler coverings, for packing in fire-proof safes, and for electric insulation where some heat resistance is necessary. Chrysotile is also used in making fire-proof rope, felt, tubes, cloth, boards, blocks, etc. *Asbestic* is a name given to short-fibred chrysotile mixed with serpentine. *Asbestine* is a pigment of which asbestos is an important ingredient, and serves to hold up other heavier pigments. Asbestos is also used for filtering in chemical work, and for this purpose the amphibole asbestos is better adapted. Many patented mixtures of asbestos and other materials, such as Portland cement, etc., are now used for making such products as asbestos wood, asbestos slate, asbestolith, etc.

Production of Asbestos. — The United States is the largest producer of manufactured asbestos products, but less than one per cent of the raw material is mined in this country. Canada is the main source of supply, and will no doubt continue so for a long time.

The production and imports from 1904 to 1908 were as follows: —

ANNUAL PRODUCTION AND ANNUAL VALUE OF IMPORTS OF ASBESTOS INTO THE UNITED STATES, 1904–1908

YEAR	PRODUCTION		VALUE OF IMPORTS		
	Quantity (short tons)	Value	Unmanufactured	Manufactured	Total
1904	1,480	$25,740	$700,572	$51,290	$751,862
1905	3,109	42,975	776,362	70,117	846,479
1906	1,695	28,565	1,010,454	65,716	1,076,170
1907	653	11,899	1,104,109	200,371	1,316,379
1908	936	19,624	1,068,322	127,548	1,195,870

The range in price for the various grades of Canadian asbestos is as follows: —

GRADE	PRICE PER SHORT TON
No. 1 crude asbestos	$275–350
No. 2 crude asbestos	150–250
Asbestos fiber (according to grading)	25–150
Fines (according to grading)	10– 25
Asbestic (a by-product) averaging in 1907	Less than $1

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BARITE

Properties and Occurrence. — Barite, the sulphate of barium, contains when pure, BaO 65.7 per cent, and SO_3 34.3 per cent. Its specific gravity is 4.3 to 4.6 and its hardness 2.5 to 3.5. It is commonly white, opaque to translucent, and crystalline, while the texture is granular, fibrous, or more rarely earthy. The common impurities are silica, lime, magnesia, ferric oxide, and alumina, but commercial grades contain usually over 95 per cent $BaSO_4$.

Barite occurs commonly as a gangue mineral in some metalliferous veins, as veins, in schists, sandstones, and limestones or sometimes as replacements of the last. In many localities, however, the limestone has weathered down to residual clay, the barite forming nodular concentrations in the same. Deposits of commercial value are known in Missouri, Virginia, Kentucky, Tennessee, and other states. Of these named the first is the most important producer.

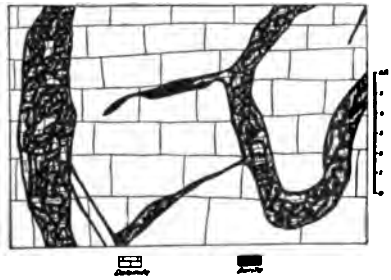

FIG. 87. — Barite veins in Potosi dolomite, southeastern Missouri. (*After Buckley, Mo. Bur. Geol. and Mines, IX.*)

Missouri (3). — Barite forms scattered deposits in Washington and adjacent counties, though many of the occurrences are clustered around Mineral Point, Washington County. The material is obtained from the Potosi (Ordovician) limestones, in which it occurs as replacement veins (Fig. 87) mixed with lead, or in residual clay with chert and drusy quartz, the whole forming a sheet-like deposit, at no great depth (Fig. 88).

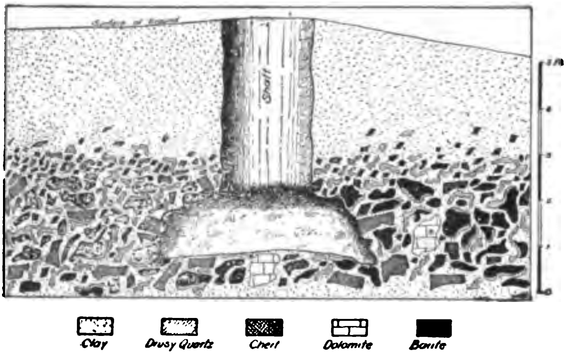

FIG. 88. — Barite deposit in residual clay near Mineral Point, Mo. (*After Buckley, Mo. Bur. Geol. and Mines, IX.*)

Virginia (11). — Barite occurs in many parts of the state (Fig. 89), but the industry has been confined mainly to a few localities.

The barite deposits may be grouped into three areas, as follows: 1. Deposits of the Triassic red shale-sandstone series, in which the barite is associated with red shales and impure limestones. It has been deposited from solution in fractures in the red shales, or more rarely as thin, tabular replacement masses in the limestone. 2. Deposits of the crystalline metamorphic area, probably for the most part of pre-Cambrian age, and in which the barite occurs either as irregular lenses of 100–200 feet diameter in limestone, or as nodules in a residual limestone-schist clay (Fig. 90). In one locality the barite fills a vein in siliceous schists, remote from calcareous rocks. 3. The mountain region of southwestern Virginia. Here the barite, which is associated with the Shenandoah limestone (Cambro-Ordovician), is found either as lumps in the residual clay, or in the fresh rock.

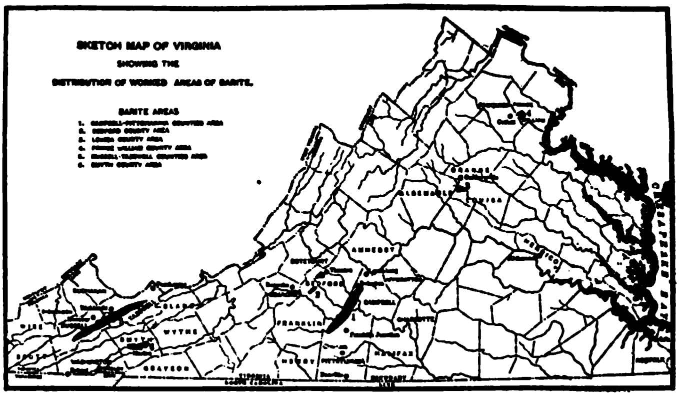

FIG. 89. — Map of Virginia showing location of worked areas of barite. (*After Watson, Min. Res. Va.*, 1907.)

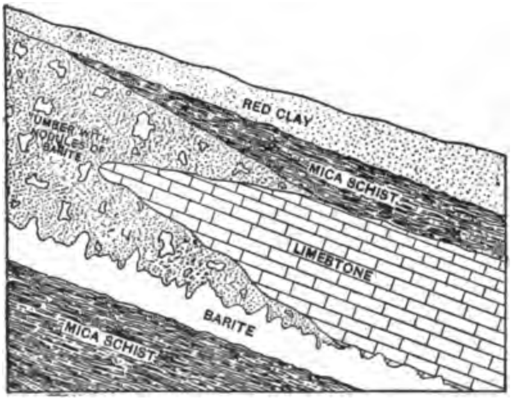

FIG. 90. — Ideal section in Bennett Barite Mine, Pittsylvania County, Va. (*After Watson, Min. Res. Va.*, 1907.)

The frequent association of the barite with limestone in all the areas is quite noticeable.

The second region is the most important producer.

Watson believes that the source of the barite is the rocks in which the deposits are now found. Thus in the Valley region it was no doubt derived from the Shenandoah limestone, while in the Piedmont area it may have come either from the crystalline schists or limestone mass. That of the Thaxton area was doubtless obtained from the silicates of the granite. The liberation and removal of the barium in solution is considered to have been accomplished by shallow circulations. The barite is always crystalline in texture.

Georgia (6). — Barite deposits are known to occur near Cartersville, Ga., associated with the Beaver (Cambrian) limestone and Weisner (Cambrian) quartzite (Fig. 91). It is thought that the barite was originally deposited by the replacement of certain beds of the shaly limestone overlying the quartzite, but it now forms nodules and masses scattered through a residual clay, and mixed with some quartzite fragments. Gravity has probably aided in concentrating the barite into workable deposits.

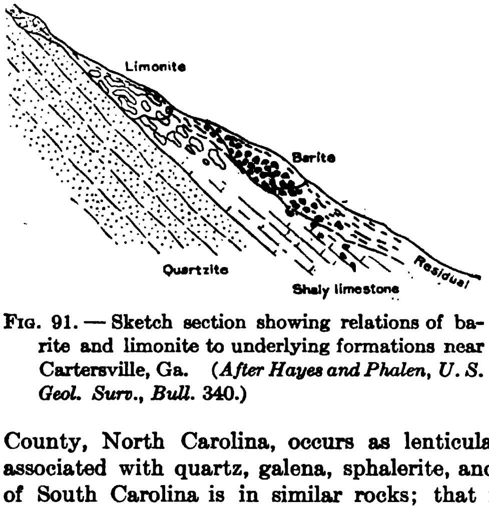

FIG. 91. — Sketch section showing relations of barite and limonite to underlying formations near Cartersville, Ga. (*After Hayes and Phalen, U. S. Geol. Surv., Bull.* 340.)

Other Occurrences. — The barite of Gaston County, North Carolina, occurs as lenticular fissure fillings in schist, associated with quartz, galena, sphalerite, and pyromorphite, while that of South Carolina is in similar rocks; that in Tennessee is in residual clay overlying the Knox dolomite (Cambro-Ordovician), and that found in Central Kentucky is in veins in the Trenton (Ordovician) and mixed with galena, fluorite, calcite, and sphalerite.

Origin of Barite. — Sulphate of barium is but slightly soluble, but is perceptibly decomposed by a dilute solution of carbonated alkali. If present in one of the silicates (feldspar) in granite it might be decomposed by sulphates of the alkalies, lime sulphate, or magnesium sulphate, resulting in precipitation of barium sulphate.

Buckley (3) believes that the Missouri barite was possibly derived from solutions of the bicarbonate, precipitated with alkaline sulphates.

Watson (11) suggested that in the case of the Virginia barite it was probably taken into solution as the soluble bicarbonate, and precipitated under favorable conditions as the insoluble sulphate. Laboratory experiments by Dickson (4) with solutions of barium carbonate on selenite crystals and pure anhydrite in presence of CO_2, and on pyrite crystals in presence of an oxidizing agent, water, caused precipitation of barium sulphate in each case.

Uses. — Barite, which is pulverized and sometimes purified by washing, is used in the manufacture of paper, for coating canvas ham sacks, in pottery glazes, and in the manufacture of barium hydroxide. Its main use perhaps is in white pigments to mix with white lead, zinc white, or a combination of both of these pigments. Although formerly regarded as an adulterant of white pigments, it is now considered to make the mixture more permanent, less likely to be attacked by acids, and freer from discoloration. *Lithophone* paint is a mixture of barium sulphate (68 per cent), zinc oxide (7.28 per cent), and zinc sulphide (24.85 per cent).

Barite is usually prepared for the market by hand sorting, crushing, washing or jigging, bleaching, and grinding. Minerals like galena, quartz, calcite, and limonite are common impurities and require separation.

Since the barite deposits are usually small and pockety, the mill must be located to permit its drawing on numerous and changing sources of supply.

Production of Barite. — The production of barite for several years is given below. The decrease in 1908 was due to the business depression of 1907.

PRODUCTION OF CRUDE BARITE IN THE UNITED STATES, 1906–1908, BY STATES, IN SHORT TONS

STATE	1906			1907			1908		
	Quantity	Value	Average price per ton	Quantity	Value	Average price per ton	Quantity	Value	Average price per ton
Kentucky	[1]	[1]	——	[1]	[1]	——	5,233	$21,501	$4.11
Missouri	28,869	$93,479	$3.24	44,039	$162,459	$3.69	16,319	56,768	3.48
North Carolina	[1]	[1]	——	5,785	18,855	3.26	[1]	[1]	——
Tennessee	5,247	8,782	1.67	20,861	37,138	1.78	8,618	12,313	1.43
Virginia	11,775	45,336	3.85	9,254	32,833	3.55	[1]	[1]	——
Other States	[2] 4,340	12,770	2.94	[2] 9,682	40,492	4.18	[2] 4,445	20,077	4.52
	50,231	$160,637	$3.19	89,621	$291,777	$3.26	34,615	$110,662	$3.20

[1] Included in other states.

[2] Includes, 1906, Alabama, Kentucky, and North Carolina; 1907, Georgia and Kentucky; 1908, Georgia, North Carolina, and Virginia.

Imports. — The imports of barium compounds for 1906 to 1908 were as follows: —

VALUE OF THE IMPORTS OF BARIUM COMPOUNDS, 1906–1908

BARIUM COMPOUND	1906	1907	1908
Witherite, barium carbonate	$55,405	$24,552	$22,159
Barium dioxide	152,403	167,519	181,533
Barium chloride	65,242	79,333	42,291
Blanc fixe, or artificial barium sulphate	61,961	85,713	73,131
	$335,011	$357,117	$319,114

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DIATOMACEOUS EARTH

Properties and Occurrence (1, 8). — This material when pure is made up of the siliceous tests of diatoms (Fig. 92). Chemically it is a variety of opal. It resembles chalk or clay in appearance, but is very much lighter than either of these, and can also be distinguished from the former substance by the fact that it does not effervesce with acid. A microscopic examination serves to identify it at once. Diatomaceous earth is commonly white or light gray in color, but may be brownish, dark gray, or even black, due to the presence

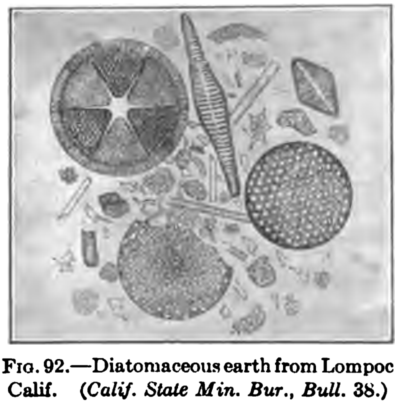

FIG. 92.—Diatomaceous earth from Lompoc, Calif. (*Calif. State Min. Bur., Bull.* 38.)

of organic matter. It is exceedingly porous. If pure, it should show little else than silica and water on analysis, but most earths show at least small amounts of other substances, and some contain a large amount of clayey impurities (see analysis VI below).

The following analyses represent the composition of a number of American earths: —

ANALYSES OF DIATOMACEOUS EARTH

	I	II	III	IV	V	VI	VII	VIII
SiO_2 . . .	86.92	72.50	86.89	80.53	81.53	63.17	82.85	86.515
Al_2O_3 . .	4.27	11.71	2.32	5.89	3.43	19.30	6.76	.449
Fe_2O_3 . .	—	2.35	1.28	1.03	3.34	6.32	2.34	.374
CaO . . .	1.60	.32	.43	.35	2.61	.06	.35	.120
MgO . . .	tr.	.83	tr.	—	—	.69	1.06	12.000
Alkalies . .	2.48	1.88	3.58	—	2.59	3.14	2.06	—
TiO_2 . . .	—	—	—	—	—	.88	1.09	—
Ign. loss . .	5.13	9.54	4.89	12.03	6.04	6.39	3.40	—
	100.40	99.13	99.39	99.83	99.54	99.95	99.91	98.458

I. Porcelain diatomaceous shale, Point Sal, Santa Barbara Co., Calif. II. Soft shale, Orcutt, Santa Barbara Co., Calif. III. Monterey, Santa Barbara Co., Calif. IV. Lake Umbagog, N. H. V. Pope's Creek, Md. VI. Wilmot, Virginia; very clayey. VII. Richmond, Virginia. VIII. Herkimer, N. Y.

Distribution in the United States. — Diatomaceous earth occurs as deposits of comparatively small extent in the bottoms of ponds, lakes, and swamps, sometimes mixed with organic matter, or it may form bedded deposits of marine origin and showing at times great extent as well as thickness. A few localities may be mentioned.

California (1, 2, 4). — Important deposits of diatomaceous earth are known to occur at a number of points in the Coast Ranges of California, but the most important, perhaps, are those found in northern Santa Barbara County. There it occurs mainly in the Monterey (Middle Miocene) and in the lower part of the Fernando (Upper Miocene) formations.

The deposits range from those of high purity, through impure shaly beds, to flinty deposits. The earth is found interbedded with volcanic ash at some localities (south of Lompoc), and with limestones at others. The thickness of the diatom deposits is often remarkable, being 2400 feet south of Harris, and 4700 feet between the Santa Ynez and Los Alamos valleys.

New York (3, 5, 6). — Although diatomaceous earth is known to occur at several localities, the only one recently worked is near Hinckley, Herkimer County, where it forms a bed 2 to 30 feet in White Head Lake. It is purified by washing and pressed into cakes.

Virginia (8). — In the Atlantic Coastal Plain, deposits of diatomaceous earth are not uncommon in the Miocene (Tertiary) formations, and those around Richmond have long been known. Along the Rappahannock River, especially below Wilmot, there are long exposures, the bluffs of the material standing out prominently in the sunlight.

Maryland. — Beds of diatomaceous earth occur at the base of the Calvert (Tertiary) formation, deposits being known in Anne Arundel, Calvert, and Charles counties. Few of them are worked, although some attain a thickness of at least 25 or 30 feet.

Other States. — Connecticut, Massachusetts, are also producers, but the deposits are of limited extent. Other occurrences are noted on the map, Fig. 79.

Uses. — Diatomaceous earth, on account of its porous character, was formerly used as an absorbent of nitroglycerine in dynamite, but little or none appears to be now employed for this purpose in the United States. It can be used for polishing powders, and as a nonconductor of heat it has been occasionally utilized for steam boiler backing, for wrapping steam pipes, and for fireproof cement. Mixed with clay, or even alone, it can be used for making porous partition brick or tile. Some of the California material can be cut into any desired shape, and used as a filter stone, or even for building purposes.

In Europe, especially in Germany, it has of late years found extended application. It has been used in the preparation of artificial fertilizers, especially in the absorption of liquid manures, in the manufacture of water glass, of various cements, of glazing for tiles, of artificial stone, of ultramarine and various pigments, of aniline and alizarine colors, of paper, sealing wax, fireworks, gutta-percha objects, Swedish matches, solidified bromine, scouring powders, papier-maché, and a variety of other articles. There is said to be a large and steadily growing demand for it.

The production is given under Abrasives, where it is included with Tripoli.

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FELDSPAR

Properties and Occurrence. — The feldspar group includes several species, all silicates of alumina, with one or more of the bases — potash, soda, and lime. These species may be divided into two groups, viz. the potash-soda feldspars, and the lime-soda feldspars, a division which is not without practical value, since the two groups differ somewhat in their fusibility and mineral associates.

Orthoclase and microcline, whose composition is expressed by the formula $KAlSi_3O_8$, are the chief representatives of the first group. Expressed in percentages their composition is SiO_2, 64.7 per cent; Ol_2A_3, 18.4 per cent; K_2O, 16.9 per cent. Soda may partly or wholly replace the potash. If the latter occurs, anorthoclase results. Potash-soda feldspars are usually pinkish to nearly white, but some, as that mined in Ontario, is a distinct reddish color. Nevertheless, even the strongly colored ones may calcine to a pure white color, and show a sufficiently low iron oxide content to permit their use in pottery manufacture.

The lime-soda feldspars, or plagioclases, present a series of compounds ranging from the soda feldspar, albite, through soda-lime feldspars, to the pure lime spar, anorthite, at the other end.

Albite, whose formula is $NaAlSi_3O_8$, has SiO_2, 68.7 per cent; Al_2O_3, 19.5 per cent; Na_2O, 11.8 per cent. Anorthite, $CaAl_2Si_2O_8$, has SiO_2, 43.2 per cent; Al_2O_3, 36.7 per cent; CaO, 20.1 per cent.

All feldspars in melting pass gradually from a solid condition to that of a very stiff fluid (5), complete fusion occurring usually about Seger cone 9 (1310° C.). A mixture of soda and potash spar seems to have a slightly lower fusing point, while the lime spar, anorthite, does not melt until 1532° C. (5).

Most of the feldspar quarried in the United States is the potash-soda type, but in some localities the soda spar, albite, may be present. If plagioclase is present in feldspar used for pottery, it is generally albite.

Feldspars are widely distributed in many igneous and metamorphic rocks, but in most cases they are so intimately mixed with other minerals, that their extraction is not commercially practicable, and it is only when found in pegmatites that they are worked.

Of these rocks, two types are recognizable, viz. the granite pegmatites, which are very coarse-grained and carry quartz, potash feldspar, muscovite, biotite, tourmaline, etc., and the soda pegmatites, which consist mainly of albite with a little hornblende. Most of the deposits worked in the United States belong to the first type, only a few from southeastern Pennsylvania and northeastern Maryland falling in the second class.

It may be mentioned here that all pegmatite deposits are not worked for their feldspar contents, some serving as sources of other minerals, such as mica, quartz, or gems. Their value as spar deposits depends on the quantity and purity of the material present.

The pottery trade demands that the spar be free from iron-bearing minerals. Muscovite is also undesirable on account of the difficulty encountered in grinding it, while the permissible limits for quartz range from 5 to 20 per cent.

In quarrying or mining some sorting is often necessary, and in those states lying south of the glaciated area the deposit may be capped with residual clay.

Distribution of Feldspar in the United States. — In the United States feldspar quarries are operated in New York, Connecticut, Maine, Pennsylvania, and Maryland. The general form of deposit is similar in all the states, but those worked in Pennsylvania and Maryland are albite spar, while the others are potash spar. The wall rock is gneiss or schist.

The following table gives the composition of feldspar from a number of localities: —

ANALYSES OF FELDSPARS

	1	2	3	4	5	6	7
SiO_2	64.7	64.98	65.40	65.23	69.63	63.11	65.95
Al_2O_3 . . .	18.4	19.18	18.80	20.09	12.30	21.65	18.00
Fe_2O_3 . . .	—	.33	tr.	.71	—	—	.12
CaO	—	tr.	none	none	.95	—	1.05
MgO	—	.25	none	none	none	—	tr.
K_2O	16.9	12.79	13.90	11.60	14.96	14.10	12.13
Na_2O . . .	—	2.32	1.95	2.00	.79	1.46	2.11
Loss on ignition	—	.48	.60	.36	.43	.40	—
Total . . .	100.0	100.33	100.65	99.99	99.06	100.72	99.36

1. Theoretical composition of pure orthoclase or microcline. 2. Norwegian feldspar, used for porcelain. 3. Pink orthoclase-microcline feldspar, from Bedford, Ont. Much used by American potters. 4. Cream-colored orthoclase-microcline feldspar, Georgetown, Me. 5. White orthoclase-microcline feldspar, South Glastonbury, Conn. 6. Pearl-gray orthoclase-microcline feldspar, near Batchellerville, N. Y. 7. Pink orthoclase-microcline feldspar, Bedford Village, N. Y.

ANALYSES OF FELDSPARS

	8	9	10	11	12	13	14
SiO_2	65.33	64.62	63.50	65.96	68.60	48.25	76.37
Al_2O_3 . . .	20.96	20.57	22.39	19.53	19.10	34.11	13.87
Fe_2O_3 . . .	.71	tr.	.36	.24	.14	—	
CaO	none	.14	2.15	.18	tr.	15.63	.26
MgO	none	2.36	none	—	.28	—	none
K_2O	10.65	1.94	3.40	12.92	9.03	—	5.24
Na_2O	1.37	10.27	6.27	1.13	2.09	1.98	3.74
H_2O	—	—	—	—	—	—	.30
Loss on ignition	—	—	1.00	—	—	—	—
Total . . .	99.02	99.90	99.07	99.96	99.24	99.97	99.78

8. Light yellow orthoclase-microcline feldspar, North Castle, N. Y. 9. Soda feldspar, Chester County, Pa. 10. White feldspar, Embreeville, Pa. 11. Potash feldspar, Woodstock, Md. 12. Potash-soda feldspar, Henryton, Md. 13. Lime-soda feldspar (bytownite), Point Corundum, near Duluth, Minn. Used for abrasives and filters, but not for pottery. (All analyses from Min. Res., U. S., 1906 : 1257, 1907.) 14. Kinkle's quarry, Bedford, N. Y., No. 3 grade, used in glass, but not for pottery. U. S. G. S., Bull. 420.

Uses (1). — Feldspar is used chiefly as a flux in the manufacture of pottery, electrical porcelain, and some enameled wares. For all these purposes it should be as free from iron as possible, but some of the ground commercial spar carries as much as 15 to 20 per cent free quartz.

Feldspar is also employed as a flux or binder in emery and carborundum wheels, and to some extent in the manufacture of opalescent glass. For the last purpose it can carry more quartz and muscovite than pottery spar, and does not have to be as finely ground, 50 to 60 mesh being sufficient.

As an ingredient of scouring soap, feldspar possesses advantages over quartz, because it is softer and less liable to scratch glass. Selected feldspar is used in the manufacture of artificial teeth.

The possibility of using feldspar as a fertilizer, because of its potash contents, has been suggested; but no commercially practicable means of extracting the desired element has as yet been found (2).

Production of Feldspar. — The production of feldspar from 1904 to 1908 is given below. The crude refers to that sold in the unground state, but all spar is crushed before use.

PRODUCTION OF FELDSPAR, 1904 TO 1908, IN SHORT TONS

YEAR	CRUDE		GROUND		TOTAL	
	Quantity	Value	Quantity	Value	Quantity	Value
1904	19,413	$66,714	25,775	$199,612	45,188	$266,326
1905	14,517	57,976	20,902	168,181	35,419	226,157
1906	39,976	132,643	32,680	268,888	72,656	401,531
1907	31,080	101,816	53,469	397,253	84,549	499,069
1908	18,840	65,780	48,400	335,138	67,240	400,918

The preceding figures do not include feldspar used for abrasive purposes.

Dealers usually divide feldspar into the following three grades:

No. 1, which is free from iron-bearing minerals, mostly free from muscovite, and contains less than 5 per cent quartz.

No. 2, which is largely free from iron-bearing minerals, and in the potash spar usually carries 15 to 20 per cent quartz.

No. 3, which is less carefully selected and may carry enough iron-bearing minerals to render it unfit for pottery purposes.

The average price in 1908 of crude feldspar used for pottery and enamel ware was about $4 per short ton f.o.b., while the average price of the ground was about $8.20 per short ton f.o.b. mills.

REFERENCES ON FELDSPAR

1. Bastin, U. S. Geol. Surv., Bull. 420, 1910. (General and United States.) 2. Cushman, U. S. Dept. Agric., Bur. Plant Industry, Bull. 104, 1907. (Fertilizer uses.) 3. Day and Allen, Amer. Jour. Sci., XIX : 98, 1905. (Thermal properties.) 4. Hopkins, Ann. Rept. Pa. State College, 1898 to 1899, Appendix, Pt. II. 5. Mathews, Md. Geol. Surv., Rept. on Cecil Co. : 217, 1902. 6. Watson, Min. Res. Va., 1907 : 275. (Va.)

FLUORSPAR

Fluorspar, or fluorite (CaF_2), contains 48.9 per cent fluorine and 51.1 per cent calcium. Its hardness is 4, its specific gravity, 3.18, and it has a pronounced octahedral cleavage. Fluorite shows a variety of colors, including white, green, purple, etc. The mineral is commonly found in veins which may be fissure fillings or replacements, and is often associated with ore minerals, especially lead and tin. Limestone is the most important wall rock of the American deposits, but in some districts granites, gneisses, or volcanic rocks may form the vein wall.

Distribution in the United States. — In the United States fluorite is found at a number of points in the Piedmont and Appalachian areas from Maine to Virginia, and is likewise noted (usually in small amounts) in many metalliferous veins of the west; but the most important producing districts are in Kentucky and Illinois. Colorado, Arizona, and Tennessee are also to be included in the producing states.

Kentucky (3, 4). — In the western Kentucky district, which is one of the largest producers of the world, the fluorite occurs as vein deposits in fault fissures cutting limestones (Pl. XXVII, and Fig.

93), sandstones, and shales of Carboniferous age. The minerals have been deposited by (1) a filling of the fissure cavity, (2) replacing the wall rock of the fissure, or (3) cementing a breccia of the same. Associated with the fluorspar are barite, calcite, galena, and sphalerite, as well as other minerals in smaller amounts. The different minerals may occur in the veins, either intimately intergrown or in separate bands; in some cases, however, only one mineral may be present in the vein. The fault fissures strike northeast and northwest, but the former carry more fluorite.

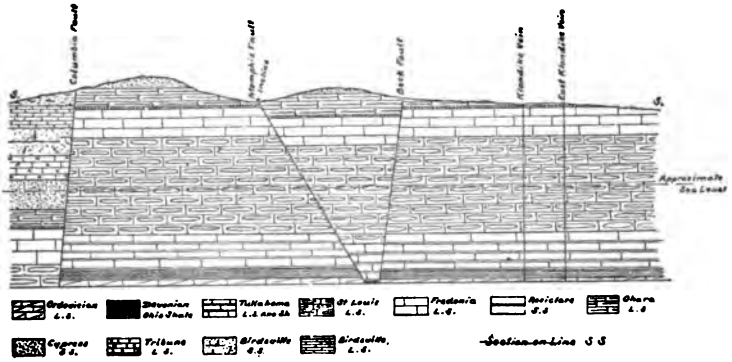

FIG. 93. — Section of Memphis mine group, along line *SS* of PL. XXVII. (*After Fohs, Ky. Geol. Surv., Bull.* 9.)

It is supposed that the fluorite has been deposited by thermal waters, which were given off during cooling by the dikes of mica peridotite which are found in the district. The fissures, fault planes, and dike contacts served as trunk channels along which the waters ascended, and from which they also spread out into the adjacent rocks. Weathering has produced a disintegration of the fluorite. The veins show a maximum width of 36 feet for gravel ore and 16 feet for lump ore.

The product of the veins is divided into lump, representing the coarse product; gravel, which is the naturally or artificially disintegrated spar, and ground fluorspar. Washing and jigging are necessary to separate clay and associated minerals. Number 1 fluorite is usually white and carries 96 per cent or more of calcium fluoride; Number 2 grade has at least 90 per cent calcium fluoride and under 4 per cent silica; while Number 3 carries from 60 to 90 per cent calcium fluoride.

Illinois. — Until 1898 the mines of Hardin and Pope counties, Illinois, were the only domestic source (1), and this area continues to be an important producer. There the deposits fill fault fissures in Lower Carboniferous limestones or sandstones. Dikes of mica peridotite also occur in the district, but not in contact with the veins. These latter in some places attain a width of 45 feet and a proven depth of 200 feet. This great width is due partly to enlargement of the fissure by solution, and partly to a replacement of the limestone walls. In the limestone footwall, the fluorspar sometimes forms a solid mass from 2 to 12 feet thick, but that on the hanging wall is less pure. The vein filling is chiefly fluorite and calcite, while associated with these are smaller amounts of galena, sphalerite, and occasionally pyrite or chalcopyrite. It is significant that the galena is slightly argentiferous.

The origin of the fluorite is somewhat doubtful, but Bain (1) believes that it has probably been derived from heated waters of either meteoric or magmatic origin which leached the mineral from some large mass of low-lying igneous rocks of which the dikes are offshoots. These heated ascending solutions are thought to have carried fluosilicates of zinc, lead, copper, iron, barium, and calcium. The dissolved compounds were probably broken up by cold descending waters, which possibly also furnished the sulphur to combine with the metals.

Colorado (2). — In eastern Colorado fluorspar occurs in considerable quantities in a belt extending from Boulder County to Custer County. The veins, in most cases, cut granites and gneisses of pre-Cambrian age that have been intruded by later dikes, especially of quartz porphyry. Metalliferous minerals are associated with the fluorite, but in several instances the latter forms most of the vein filling. The deposits have thus far not been extensively developed, and much of the material lies rather far from the railroad. The three producing localities are Jamestown, Boulder County; Evergreen, Jefferson County; and near Rosita, Custer County.

Other States. — Tennessee (3, 5) fluorspar comes from Smith, Trousdale, and Wilson counties of that state; while that obtained in Arizona (5) is mainly from the Castle Dome district, Yuma County.

Imports. — Considerable gravel spar is produced as tailings from the English lead mines and shipped as ballast to the United States, and has entered duty free, thus competing with the American product as far west as Pittsburg. It is high in silica and is almost entirely consumed by open hearth steel makers. The estimated imports for 1908 were not over 22,000 short tons.

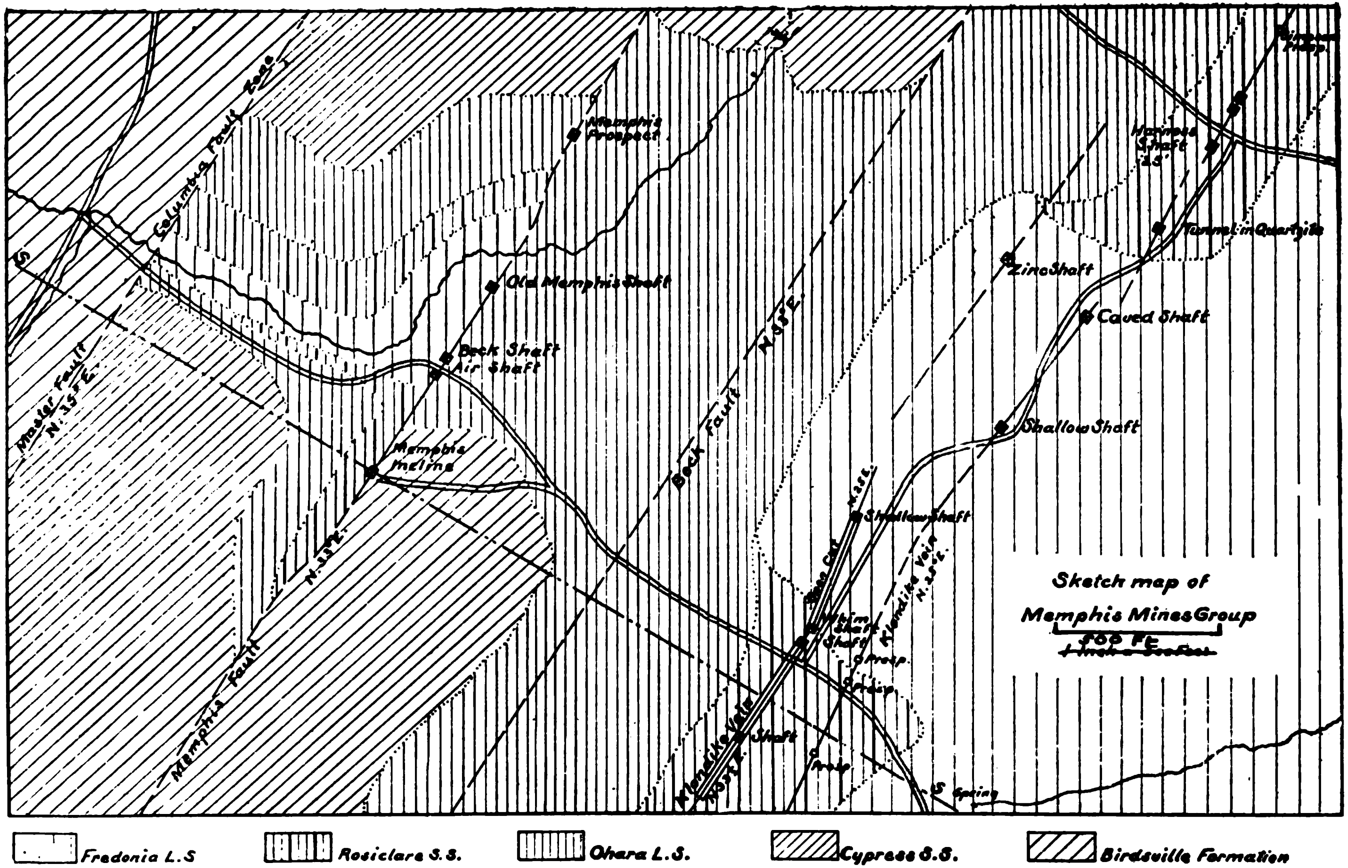

PLATE XXVII. — Map of portion of Kentucky fluorite district. (*After Fohs, Ky. Geol. Surv., Bull. 9.*)

Analyses of Fluorspar. — The following analyses (3, 2) will indicate the variation in composition of the American product: —

ANALYSES OF FLUORSPAR

LOCALITY	CaF_2	SiO_2	$CaCO_3$, $MgCO_3$	Fe_2O_3, Al_2O_3
Memphis Mines, Ky.	99.95	tr.	tr.	—
Hodge Mines, Ky.	98.30	.21	.98	—
Nancy Hanks Mines, Ky. . . .	96.00	.71	3.29	tr.
Gravel Fluorspar	95.08	1.90	—	—
Rosita, Colorado	86.75	9.3	—	4.2
Jamestown, Colorado	60.9	27.	—	n.d.
	76.05	19.8	—	4.2
	86.75	8.60	—	4.46
Marion, Ky.	96.01	1.9	—	1.88
	84.25	2.98	10.28	1.28
Fairview, Ill.	88.85	3.4	—	1.45

Uses. — Fluorspar was formerly used chiefly for making hydrofluoric acid, but not more than 5 to 10 per cent of the domestic product is now employed for this purpose, while increasing quantities are sold for the manufacture of opalescent glass. The greatest demand for it, however, is as a flux in iron manufacture, since it saves from 3 to 5 per cent more iron than limestone flux, reduces the sulphur and phosphorus contents, and increases the tensile strength of the metal. On account of its valuable reducing properties, it is also used in making spiegeleisen, in foundry work, and in cupola furnaces.

It is also used in the manufacture of enamels, glazes, and fireproof ware, for apochromatic lenses, for gems, cheap jewelry, paper weights, and for carbon electrodes for flaming arc lamps. Its use as a flux in cement manufacture has been discontinued.

Production of Fluorspar.—The table on page 232 gives the quantity and value of fluorspar marketed from 1906 to 1908.

The fluorspar is prepared for market by hand sorting, crushing, jigging, and sometimes fine grinding. The grades produced are:

1. American lump No. 1, with under 1 per cent silica, and sold mainly to glass, enameling, and chemical industries.

2. American lump No. 2, which includes colored spar, and may run as high as 4 per cent silica, though usually sold under a 3 per cent guaranty. It is used by blast furnaces in the production of

ferrosilicon and ferromanganese, and in basic open hearth steel furnaces.

3. Gravel spar, including all with over 4 per cent silica, and spar mixed with calcite. It is used in iron and brass foundries.

FLUORSPAR MARKETED IN 1906 to 1908, IN SHORT TONS

STATE	GRAVEL		LUMP		GROUND		TOTAL QUANTITY	TOTAL VALUE
	Quantity	Value	Quantity	Value	Quantity	Value		
1906								
Colorado . .	—	—	—	—	—	—	[1]	[1]
Illinois . . .	—	—	23,739[2]	$113,399[2]	4,529	$47,224	28,268	$160,623
Kentucky . .	—	—	8,207[1]	40,084[3]	4,321[3]	43,318[3]	12,528[4]	83,492[4]
Total . .	—	—	31,946	$153,483	8,850	$90,542	40,796	$244,025
1907								
Colorado . .	3,300	$11,400	—	—	—	—	3,300	$11,400
Illinois . . .	18,610	83,259	3,038	$22,828	3,480	$35,884	25,128	141,971
Kentucky . .	14,276	71,376	—	—	6,782	62,595	21,058	133,971
Total . . .	36,186	$166,035	3,038	$22,828	10,262	$98,479	49,486	$287,342
1908								
Colorado . .	745[5]	$4,518	—	—	—	—	745	$4,518
Illinois . . .	21,332	96,315	6,189	$33,267	4,206	$43,256	31,727	172,838
Kentucky . .	2,840	14,226	307	1,828	3,176	32,588	6,323	48,642
Total . . .	24,917	$115,059	6,496	$35,095	7,382	$75,844	38,795	$225,998

[1] Included in Kentucky.
[2] Includes crude and gravel spar.
[3] Includes crude and gravel spar from Colorado and Tennessee.
[4] Includes production from Colorado and Tennessee.
[5] Includes a small production of lump spar from Arizona.

REFERENCES ON FLUORSPAR

1. Bain, U. S. Geol. Surv., Bull. 255, 1905. (Ill.) 2. Burchard, U. S. Geol. Surv., Min. Res. for 1908. (Colo.) 3. Fohs, Ky. Geol. Surv., Bull. 9, 1907. (Ky. and General.) 4. Fohs, Amer. Inst. Min. Engrs., Bi-Mon. Bull., April, 1909. (Ky. spar and use in iron industries.) 5. Pratt, U. S. Geol. Surv., Min. Res., 1901 : 879, 1902. (Ariz.) 6. Ulrich and Smith, U. S. Geol. Surv., Prof. Pap. 36, 1905. (Ky.) 7. Watson, Va. Geol. Surv., Bull. 1 : 42, 1905. (Va.)

FOUNDRY SANDS

Definition. — Under the term *foundry sand* there are included (1) sands for making the mold proper into which the metal is cast, and (2) core sand, utilized for making the cores which occupy the hollow spaces of the cast piece.

The molding sands proper are usually of finer texture and more loamy character than the core sands, still the two grades overlap, and both show considerable range of texture. In selecting molding sands, the fine-grained ones are used for small castings, while the coarser grades are employed for heavy castings. The core sands have but little cohesiveness, owing to their lack of clayey matter, and hence require the addition of an artificial binder.

Requisite Properties. — The requisite physical qualities of foundry sands are: 1. sufficient cohesiveness to make the grains cohere when pressed together to form the parts of the mold, the deficiency in this respect in core sands being supplied by artificial binders; 2. sufficient refractoriness to prevent extensive fusion in the sand when exposed to the heat of the molten metal; 3. texture adapted to the grade of casting to be poured in it; 4. sufficient porosity and permeability to permit the escape of the gases given off by the cooling metal; 5. durability, or sufficient length of life, to permit as much of the sand as possible being used over again.

The laboratory examination of a molding sand might properly include the determination of (1) its texture (by mechanical analysis), (2) porosity, (3) permeability (by aspirator method), (4) average fineness (by aspirator method),[1] (5) tensile strength, and (6) refractoriness.

Chemical analyses of foundry sands are in most cases of little value, mainly because they shed no light on the physical properties. A few are, however, given below: —

CHEMICAL ANALYSES OF FOUNDRY SANDS

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	H_2O	MOIST
1.	81.59	6.46	4.94	.14	.22	1.19	.59	1.90	1.63	1.46
2.	66.12	16.54	4.46	.40	.22	2.67	.35	.14	4.90	4.15
3.	79.36	9.36	3.18	.44	.27	2.19	1.54	.34	2.02	.74
4.	79.38	9.38	3.98	1.40	.54	1.80	1.04	.44	2.50	.80
5.	71.60	11.49	7.81	.65	.95	1.42	1.27	—	4.00	
6.	86.80	3.05	5.32	.15	.65	.83	.04	—	3.25	
7.	84.28	4.50	6.10	tr.	.72	.91	.39	—	3.10	
8.	79.41	12.47	.80	.99	.81	1.56		—	3.96	
9.	57.63	10.03	.88	11.16	5.63	.01		—	14.66[2]	
10.	84.86	7.03	2.18	.62	.98	Undet.		—	2.20	
11.	82.90	8.21	2.90	.62	.00	Undet.		—	2.85	
12.	81.57	11.52	2.74	1.49	.18	—		—	2.50	

1. Fine sand for light castings, Richmond, Va. 2. Coarse, gravelly core sand, Richmond, Va. 3. Stove plate sand, Albany, N. Y. 4. Stove plate sand, Newport, Ky. 5. "Philadelphia" brass sand. 6. Lumberton, N. J., brass sand (mild). 7. Lumberton, N. J., brass sand (strong). 8. Upper sand bed, Rockton, Ill. 9. Lower sand bed, Rockton, Ill. 10. Sand for medium weight castings. 11. Coarse sand for heavy castings. 12. Stove plate sand, Conneaut, O. All quoted from Ref. 6.

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[1] The average fineness may be determined in other ways, but these are less accurate. See Ref. 6.

[2] Includes CO_2.

The following table gives the mechanical analysis, specific gravity, and porosity of a number of samples of foundry sand.

PHYSICAL TESTS OF FOUNDRY SANDS

No.	PER CENT RETAINED ON						CLAY	SPECIFIC GRAVITY	PER CENT PORE SPACE	AVERAGE SIZE OF GRAIN IN TERMS OF SIEVES, ASPIRATOR METHOD
	20 MESH	40 MESH	60 MESH	80 MESH	100 MESH	250 MESH				
1.	6.84	6.61	40.09	8.98	23.82	12.56	1.06	2.68	36.2	91
2.	.96	12.42	34.41	4.31	7.50	18.29	22.06	2.61	38.8	714
3.	.30	.77	4.52	1.63	5.35	57.95	29.44	2.59	40.9	770
4.	4.69	13.34	23.96	5.01	11.95	18.22	22.79	2.66	45.0	222
5.	.09	.45	1.51	.31	.74	66.79	30.08	2.67	42.2	1429
6.	.13	.59	20.10	5.81	15.89	33.35	24.09	2.62	—	—
7.	.33	.18	.55	.24	5.47	87.92	5.36	2.65	43.0	344
8.	2.51	6.16	16.49	4.74	11.30	32.37	26.39	2.62	42.9	361
9.	.27	.54	1.21	.32	1.21	69.46	26.97	—	—	—
10.	.08	.20	.17	.00	.14	87.56	11.82	2.7	46.7	714
11.	1.51	1.26	1.27	.56	6.27	71.69	16.52	—	—	—
12.	42.48	12.90	6.16	.85	1.70	8.58	26.44	—	—	—
13.	3.03	1.41	.97	.40	2.61	48.32	41.87	—	—	—
14.	—	.36	6.56	3.52	21.22	64.84	2.56	—	—	—
15.	.4	16.54	56.24	5.60	5.20	2.60	13.34	2.58	40.41	—
16.	1.32	14.02	28.68	5.62	10.24	14.12	25.02	2.55	39.52	—
17.	.04	.06	.12	.06	.12	80.12	19.22	2.66	43.43	—
18.	4.5	32.0	23.0	16.0	9.5	15		2.613	45.1	—
19.	5.5	25.5	11.5	14.5	12.0	31		—	39.5	—

1. Fine core sand, Jackson, Mich. 2. Sand for general work, Zanesville, O., district. 3. Riverside, Mich. 4. Core sand, Niles, Mich. 5. Stove plate sand, Conneaut, O. 6. Sand for general work, Vineland, Mich. 7. Leoni, Mich. 8. Sand for heavy work, Battle Creek, Mich. 9. No. 5 sand, Newport, Ky. 10. No. 3 sand, Akron, O. Nos. 1–10 quoted from Ref. 6. 11. Sand for general work, Manchester, Va. 12. Coarse sand, Richmond, Va. 13. Petersburg, Va. Nos. 11–13 quoted from Ref. 6. 14. Sand for small castings, Berlin, Wis. 15. Core sand for heavy castings, Janesville, Wis. 16. Sand for heavy castings, Kenosha County, Wis. 17. No. 4 sand, for malleable and gray iron, and brass, Waterford, Ill. Nos. 14–17 quoted from Ref. 4. 18. Lumberton, N. J. 19. Strong sand, Hainesport, N. J. Nos. 18–19, Ref. 2.

Distribution in the United States. — Many thousands of tons of foundry sand are used annually by foundries, scattered all over the United States. In most cases these represent natural mixtures, but for some grades of work, especially steel casting, artificial mixtures of quartz, clay, etc., are used.

Sands for cores and molds for general work are widely distributed and obtainable from many surface formations, usually of recent age; but the finer-grained sands, such as are required for stove plate and brass casting, are of rarer occurrence. The regions around Albany, New York, Conneaut, Ohio, Newport, Kentucky, Valparaiso, Indiana, etc., are noted for their supplies of the finer grades of molding sands. New Jersey is also an important producer, but there the sand is obtained largely from Cretaceous and Tertiary deposits. In the digging of molding sand, careful sorting is sometimes necessary, the deposit of good sand being often thin, or of irregular thickness, and interbedded with other sands of no value, although closely resembling the good material.

The literature on molding sands is not extensive.

The value of molding sand produced in the United States in 1908 is reported as $1,342,802, but these figures are probably only approximate.

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FULLER'S EARTH

Properties. — Fuller's earth (7) may be regarded as a peculiar type of clay which has a high absorbent power for many substances, on which account it is of value for decolorizing oil and other liquids. Its color and chemical composition are variable, and its specific gravity ranges from 1.75 to 2.5. The quantitative analysis shows it to differ chiefly from common clay in having a relatively higher percentage of combined water.

The following analyses represent the composition of fuller's earth from different localities, but it should be emphasized that they are of little value in judging the quality of the earth:—

CHEMICAL ANALYSES OF FULLER'S EARTH

	I	II	III	IV	V	VI	VII
SiO_2 . .	47.10	62.83	67.46	58.72	74.90	54.32	63.19
Al_2O_3 . .	16.27	10.35	10.08	16.90	10.25	18.88	18.76
Fe_2O_3 . .	10.00	2.45	2.49	4.00	1.75	6.50	7.05
CaO . .	2.63	2.43	3.14	4.06	1.30	1.00	78
MgO . .	3.15	3.12	4.09	2.56	2.30	3.22	1.68
K_2O . .	—	.74	—	2.11	1.75	4.21	.21
Na_2O . .	—	.20	—	—	—	—	1.50
H_2O . .	20.85	7.72	5.61	8.10	5.80	—	7.57
Moisture .	—	6.41	6.28	2.30	1.70	11.86	—
Total .	100.00	96.25	99.15	98.45	99.75	99.99	100.74

I. Woburn sands, Eng. (Yellow.) II. Gadsden County, Fla. III. Decatur County, Ga. IV. Fairburn, S. Dak. V. Sumter, S. Ca. VI. Bakersfield, Calif. VII. Alexander, Ark. All quoted from Ref. 7.

The cause of the bleaching power of fuller's earth still remains to be explained, but Parsons (3) has suggested that the phenomenon is one of simple absorption. Lime carbonate seems to injure the bleaching power of the earth, and in some cases appears to be counteracted somewhat by acid treatment. A practical test affords the only satisfactory method of determining the value of fuller's earth.

Distribution in the United States (1, 3, 7). — In former years nearly all of the fuller's earth used in the United States was imported from England, where large deposits of this material exist; but occurrences are now known in a number of states, including Florida, Georgia, Alabama, Arkansas, Colorado, South Carolina, etc.

At most localities the earth is found interbedded with sands or clays, which may sometimes differ from it but little in appearance.

Fuller's earth is not confined to any particular formation, but the known deposits occur in sedimentary rocks ranging from the beginning of the Mesozoic up to the Pleistocene. In Gadsden County, Florida (5, 8) and in Decatur County, Georgia (8), for example, it is obtained from the upper Oligocene of the Tertiary, the former locality being the most important in the country. The earth from this region is used for bleaching mineral oils.

Production of Fuller's Earth. — The domestic output has never been large, and much is still imported from England.

PRODUCTION OF FULLER'S EARTH IN UNITED STATES FROM 1906 TO 1908

	SHORT TONS	VALUE
1906	32,040	$265,400
1907	32,851	291,773
1908	29,714	278,367

REFERENCES ON FULLER'S EARTH

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GLASS SAND

Glass sand is obtained from quartzose sands, sandstones, or quartzites. When sand is employed, it is sometimes necessary to put it through a washing process in order to separate the impurities, while in the case of sandstone or quartzite, at least a preliminary crushing and screening are usually necessary.

Chemical Composition.[1]—Since silica is the major ingredient of the sand, it influences the character of the ware to a marked degree. Sand with impurities is therefore to be avoided, especially if it is to be used for the higher grades of glassware. Chemical analysis of almost any sand may show at least traces of iron oxide, alumina, titanium oxide, lime, magnesia, and organic matter, but most of these are included in mineral grains other than quartz.

Iron oxide, even in small amounts, colors the glass green, and is avoided by a selection of the whitest sand, although whiteness does not necessarily indicate freedom from impurities. Washing may remove much of the iron, and the iron color may also be counteracted to some extent by the addition of arsenic. Magnesia causes trouble by rendering the batch less fusible, but it is more apt to be introduced through the limestone than the sand. Clay is undesirable, since it tends to cloud the glass.

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[1] Frink (Ref. 14) believes that many of the views held regarding allowable limit of MgO and Al_2O_3 are incorrect, and these substances are less harmful than is commonly imagined.

CHEMICAL ANALYSES OF GLASS SANDS

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO		TOTAL
1. Ottawa, LaSalle County, Ill.	99.45	.30		.13	tr.	—	99.88
2. Utica, Ill.	99.57	.283	.0903	.0197	.002	—	99.97
3. Klondike, Mo.	99.97	.03	—	—	—	—	100.00
4. Grays Summit, Mo.	99.839	—	.0014	—	—	H O .154	99.9944
5. Everton, Boone Co., Ark.	99.55	.13	.09	—	—	—	99.77
6. Flora, Grant Co., Wis.	99.17	.25	.22	—	—		99.64
7. Coxville, Ind.	98.61	.74	.22	.12	tr.	Ign. .32	100.01
8. Tip Top, Ky. (selected)	98.87	.21	.08	.24	.12	Und. .48	100.00
9. Massillon, O.	97.50	1.50	.50	—	.50	—	100.00
10. Niles, O.	99.915	.062	.0019	.021	tr.	—	99.999
11. Berkeley, W. Va. (Oriskany sandstone)	98.99	.7717	.0383	—	—	—	99.80
12. 4 m. from Hancock, W. Va. (Medina sandstone)	99.30	.5186	.0314	—	—	—	99.85
13. Columbia, Pa. (Oriskany)	99.5044	.1337	.2989			Loss etc. .062	99.9999
14. Cheshire, Mass. (Cambrian)	99.46	.48		.06			100.00
15. Lewiston, Pa. (Oriskany)	98.84	.17	.34	tr.	tr.	Ign. .23	99.58
16. Hanover, N. J. (Tertiary)	97.705	.755	.15	.955	.442		100.007
17. Clayton, Ia. (Ordovician)	98.85	.46	.995	.21		Loss etc. .384	99.999
18. W. Vienna, N. Y. (Pleistocene)	98.6	.17	.23		tr.		99.00

Nos. 1–6, Ref. 3; Nos. 7–10, Ref. 4; Nos 11–12, Ref. 10.

Physical Properties (3). — Contrary to the belief of glass manufacturers that rounded grains are best, much good glass is made from sands of angular or subangular grain. Uniformity of grain is highly desirable, and should range between 30 and 120 mesh. If larger than 30 mesh, the sand is more difficult to fuse; while if finer than 120 mesh, it is said to " burn out " in the batch.

Few mechanical analyses of glass sands have been published, but the following will serve to show the texture of several from different localities (2, 3).

MECHANICAL ANALYSES OF GLASS SANDS

LOCALITY	SAMPLE	PASSES 20 MESH	PASSES 40 MESH	PASSES 60 MESH	PASSES 100 MESH
Ottawa, Ill. . .	Finest grained . .	100	100	92	25
Ottawa, Ill. . .	Coarsest grained	99	6	1 –	0
Ottawa, Ill. . .	Crude, direct from pit.	99 +	23	3	1 –
Utica, Ill. . . .	Crude from car .	99 +	45	11	3
Klondike, Mo. .	Extra qualtiy . .	100	90	15	1
Grays Summit, Mo.	Finished product	100	92	25	2
Grays Summit, Mo.	Crude, from quarry.	100	88	55	1 –
Crystal City, Mo.	Prepared . . .	99 +	23	13	1
Crystal City, Mo.	Average mine run	100	55	20	1
Berkeley Springs, W. Va.	Crushed sandstone, finished product	100	98	25	1 –
Everton, Ark. .	Not worked . .	99 +	97	50	10
Flora, Wis. . .	Not worked . .	99 +	80	40	15

Distribution of Glass Sand. — Sand for glass making is obtained from a number of different geological formations, ranging from Cambrian to Pleistocene. Those obtained from the Pleistocene deposits, as in New York (12), are not as a rule of high purity, but those from the Tertiary and Cretaceous formations are of better quality. In New Jersey there are extensive pits in the Tertiary, around Bridgeton (11), the material being used in the glass works of southern New Jersey and southeastern Pennsylvania. Large pits have also been opened in the Raritan formation of the Cretaceous along the Severn River in Maryland. The Oriskany sandstone is found to be of high purity in West Virginia between Berkeley Springs and a point on the border near Hancock, Maryland, the locality having been worked for a number of years (10). Sandstones of the same age are also worked in Pennsylvania (6, 8).

The glass-sand industry of Illinois (2), is developed mainly in La Salle County, the rock used being the St. Peter (Ordovician) sandstone. Much of it is very soft. Sandstone of similar age is worked in Missouri (1, 2), in a belt between Klondike on the Missouri River and Crystal City on the Mississippi River. Indiana (4) contains sandstone suitable for glass manufacture in the Silurian, Devonian, Carboniferous, and Tertiary formations, but most of it comes from the Mansfield sandstone of the Carboniferous in the southwestern part of the state. Beds of high-grade sandstone occur interbedded with Silurian limestones in northwestern Ohio (4), but the most important deposits are found in the Mississippian, Pottsville, and Lower Coal Measures in the eastern portion of the State.

Production of Glass Sand. — About 19 states report a production of glass sand, but all of the material may not be used in glass manufacture. The production of the 6 leading producers as well as the total for the United States is given below.

QUANTITY AND VALUE OF GLASS SAND IN UNITED STATES 1906 TO 1908

STATE	1906		1907		1908	
	SHORT TONS	VALUE	SHORT TONS	VALUE	SHORT TONS	VALUE
Pennsylvania . . .	342,967	$510,910	370,977	$489,989	405,028	$484,353
Illinois	238,178	156,684	235,716	152,619	194,722	139,172
West Virginia . . .	158,093	227,225	171,338	225,003	145,782	174,834
Missouri	101,862	65,393	138,483	92,898	111,517	83,100
Ohio	71,329	71,246	95,449	104,127	92,487	94,825
New Jersey	102,658	83,031	87,140	73,914	56,775	46,379
Total United States .	1,089,430	$1,208,788	1,187,296	$1,250,067	1,093,553	$1,134,599

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CHAPTER XI

MINOR MINERALS—GRAPHITE MONAZITE

GRAPHITE

Properties and Occurrence.—Graphite, or black lead, as it is often termed popularly, is a form of carbon, of which two varieties are generally recognized, especially in the trade. The first of these, the *crystalline*, has a lamellar or flaky structure, and is of high purity, while the other form, which is classed as *amorphous*, lacks crystalline structure, and may be quite impure. However, even the purest graphite may contain at least a few tenths per cent ash and volatile matter, and commercial graphite often contains an appreciable content of impurities. Those containing 90–95 per cent graphitic carbon meet the requirements of the general trade, but for many purposes, especially paint-making, graphites with as low as 30 to 35 per cent graphitic carbon can be employed.

The following analyses of graphite from a number of localities (6) show the variation in its composition, but probably do not in all cases represent commercial samples.

Analyses of Graphite

Localities	Sp. Grav.	Volatile Matter	Carbon	Ash
Cumberland, first quality	2.3455	1.10	91.55	7.35
Passau, Bavaria	2.3032	7.30	81.08	11.62
Passau, Bavaria	2.3108	4.20	73.65	22.15
Mugrau, Bohemia	2.1197	4.10	91.05	4.85
Ceylon crystals	2.3501	5.10	79.40	15.50
Ceylon, commercial quality	2.2659	5.20	68.30	26.50
Gulf of Spencera, S. Australia	2.3701	2.15	25.75	72.10
Gulf of Spencera, S. Australia	2.2852	3.00	50.80	46.20
Buckingham, Can.	2.2863	1.82	78.48	19.17
Madagascar	2.4085	5.18	70.69	24.13
Pissic, Dep. Hautes Alpes	2.4572	3.20	59.67	37.13
Ural Mts., Russia	2.1795	.72	94.03	5.25
Ticonderoga, N.Y., vein graphite	2.2647	.818	97.422	1.76

Graphite is usually easily recognized by its peculiar physical properties, such as extreme softness, steel-gray to blue-black color, greasy feel and black streak. The specific gravity is 2.20 to 2.27. Molybdenite is the only mineral with which it might be confused, but this has a bluish or greenish tinge and a greenish streak.

Distribution of Graphite in the United States. — Crystalline graphite is widely distributed in the United States, occurring in contact zones between igneous and sedimentary rocks, in metamorphic rocks, etc., but the known deposits of commercial value are few in number.

Most of the domestic supply has been obtained from New York State.

New York (4, 10, 11, 12). — The producing mines are located on the southeastern side of the Adirondacks in Essex, Warren, Washington, and Saratoga counties, and the state leads all others in its production of graphite, partly because of the steady production of one large mine.

The graphite occurs in the following ways: 1. In pegmatite veins, forming bunches, associated chiefly with quartz, but also feldspar, pyroxene, hornblende, mica, calcite, scapolite, apatite, sphene, etc. This type of deposit is of little commercial value. 2. Veinlets of graphite with quartz in gneiss. 3. Graphitic quartzites, representing metamorphosed pre-Cambrian sediments. These are the most important type. 4. Graphitic disseminations in Algonkian limestones.

At the American Graphite Company's mine, which is representative of 3, the material worked is a medium-grained, quartz-graphite schist, which averages 6.25 per cent graphitic carbon. The associated minerals are quartz, mica, and apatite. The graphite rock varies from 3–20 feet in thickness, and is overlain by garnet gneiss.

Rhode Island (5). — Amorphous graphite, graphitic anthracite, or graphitic shale, as it has been variously called, has been known for many years to occur in the metamorphosed Carboniferous rocks near Providence and Tiverton, Rhode Island, but the production has been irregular. At the Cranston Mines near Providence, which are the largest, the section shows a series of interbedded, sandy, carbonaceous, and graphitic shales, something over 300 feet thick, all folded and perhaps faulted. The main graphitic bed is 30 feet thick.

The following analyses represent the composition of an average (1) and a selected (2) specimen respectively.

ANALYSES OF GRAPHITIC SHALE FROM CRANSTON MINES

	1	2
Volatile	5.92	7.86
Graphitic carbon	40.76	25.27
Ash	53.32	66.87
Total	100.00	100.00

The material is used chiefly for paint.

Pennsylvania (8). — Crystalline graphite is also mined in Chester County, Pennsylvania, where it forms two layers from 4 to 6 feet thick in decomposed mica schist.

Alabama (14). — Crystalline graphite is found in granites and schists in Clay, Chilton, and Coosa counties. In Clay County, for example, the graphite is uniformly disseminated throughout a zone of mica-free weathered granite, ten miles long and several hundred feet wide. Its depth has been proven to 75 feet, with an average of 4.5 per cent graphite. A graphitic clay found in the slightly crystalline schists of the Palæozoic area of Clay and Tallapoosa counties is used as a lubricant.

New Mexico (3). — Amorphous graphite is known to occur in the cañon of the Canadian River, about 7 miles southwest of Raton. The bed, which is nearly horizontal, has been traced laterally into the principal bituminous coal seam of the Raton field, and that portion which is graphitized owes its character to diabase intrusions, the change being most complete where the bed was fractured and the diabase forced into it. The graphite is said to occur in pockets or irregular masses in the diabase, and is columnar normal to the faces of the igneous rock. It has been mined somewhat and sold for the manufacture of mineral paint.

Other States. — Developments of graphite have been made in other states, such as Michigan, Wisconsin, Virginia (17), Montana (13), Wyoming (2), Maine (15), Georgia (9), etc., but the output is not steady.

Origin of Graphite. — There seems no doubt that graphite shows a somewhat diverse mode of origin.

Where the material occurs in disseminated form in schists or quartzites, as in the Adirondacks, and the sedimentary origin of these rocks is clearly proven, there is little doubt that the graphite represents original carbonaceous material that has been changed to its present form by dynamic or contact metamorphism.

Graphite has in some cases been formed by the heat of igneous intrusions acting on coal-beds, as in New Mexico (q.v.), or in Central Sonora, Mexico, where coal-beds up to 24 feet thickness, inclosed in sandstone, have been metamorphosed by granite.

In other localities, where the graphite occurs in pegmatite veins as in some Ticonderoga, New York, deposits, Ceylon, or in Maine, or where it is found in lenticular enrichments associated with limestone in a decomposed gneiss near granite contact, as at Passau, Bavaria, a different explanation is required.

In these it seems probable that while the graphite must have been introduced in vaporous form, it may have been derived from two possible sources. Thus it might have been given off by igneous rocks during cooling, or else represent carbonaceous matter from neighboring sediments, which has been vaporized by heat, and migrated during metamorphism.

Graphite is known to occur in small quantities in some granites, and has been sparingly noted in other igneous rocks, but in some of these it may not be indigenous.

Uses. — On account of its refractoriness and high heat conductivity, graphite is employed in the manufacture of crucibles for use in the steel, brass, and bronze industries. For making these it is mixed with clay and some sand. Ceylon graphite is specially suitable for this class of work, because of its peculiar fibrous structure. Amorphous graphite has not given success in crucible work. In addition graphite is employed for making stove polish, foundry facings, paint, lead pencils, lubricating powder, glazing, electrotyping, steam piping, for adulterating fertilizers, coloring and glazing coffee beans or tea leaves, etc.

Both amorphous and crystalline graphite can be used for lubricating purposes. The use of graphite for pencil manufacture, though an early one, and perhaps the best known, consumes but a small percentage (under 10 probably) of the world's supply. For this purpose amorphous graphite is demanded, and while Bohemian and Bavarian graphite were originally used, Sonora, Mexico, now supplies American manufacturers with all they need.

Graphite is also made artificially from anthracite coal, but its introduction has not seriously affected the market for the natural product.

Crystalline graphite is put through a concentrating process before shipment to market. This is necessary in order to free it from the associated minerals. Both wet and dry methods of separation are employed, while more recently air separation has been tried with some success.

Production of Graphite. — The domestic production of crystalline graphite does not form more than a small proportion of the entire consumption. In the two following tables are given the production by states in 1908, and the total United States production from 1904 to 1908.

PRODUCTION AND VALUE OF NATURAL GRAPHITE IN THE UNITED STATES, 1908, BY STATES

STATE	AMORPHOUS		CRYSTALLINE		TOTAL	
	Quantity	Value	Quantity	Value	Quantity	Value
	Short tons		*Pounds*		*Short tons*	
Alabama	453	$33,750	——	——	453	$33,750
New York	——	——	1,932,000	$116,100	966	116,100
Pennsylvania . . .	——	——	356,000	16,740	178	16,740
Other states[1] . . .	990	41,500	——	——	990	41,500
	1,443	$75,250	2,288,000	$132,840	2,587	$208,090

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[1] Includes Alaska, Colorado, Michigan, Nevada, New Mexico, and Wisconsin.

PRODUCTION OF NATURAL GRAPHITE, 1904–1908

YEAR	AMORPHOUS		CRYSTALLINE		TOTAL	
	Quantity	Value	Quantity	Value	Quantity	Value
	Pounds		*Short tons*		*Short tons*	
1904	5,681,177	$238,447	16,927	$82,925	19,768	$321,372
1905	6,036,567	237,572	21,953	80,639	24,971	318,211
1906	5,887,982	238,064	16,853	102,175	19,797	340,239
1907	4,947,840	171,149	26,803	125,821	29,277	296,970
1908	2,288,000	132,840	1,443	75,250	2,587	208,090

The imports of graphite and the production of artificial graphite for the same period as above are also given.

YEAR	IMPORTS NATURAL GRAPHITE		ARTIFICIAL GRAPHITE		
	Quantity	Value	Quantity	Value	Price per Pound
	Short tons		*Pounds*		*Cents*
1904	14,195	$905,581	3,248,000	$217,790	6.70
1905	17,457	983,034	4,591,550	313,980	6.83
1906	25,487	1,554,212	5,074,757	337,204	6.64
1907	22,939	1,777,389	6,590,000	481,239	7.30
1908	11,456	762,367	7,385,511	502,667	6.80

The world's production in 1907 is given below: —

World's Production of Graphite in 1907

Country	Short Tons	Value	Country	Short Tons	Value
United States . . .	29,277	$296,270	Italy	12,125	61,374
Austria	53,013	387,930	Japan	115	5,222
Canada	579	16,000	Mexico	3,530	54,339
Ceylon	36,406	2,889,596	Norway	1,543	14,974
France	138	1,206	Queensland . . .	34	965
Germany	4,409	47,671	Sweden	36	946
India	2,725	35,949			
			Total	143,930	$3,797,142

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LITHIUM

The two minerals most commonly used as a source of lithium are *Lepidolite* ($KLi[Al(OH,F_2)]Al(SiO_3)_3$) and *Spodumene* ($LiO_2$, Al_2O_3, 4 SiO_2). The largest deposits of lepidolite at present known in the United States are found near Pala, California. Spodumene occurs in some quantities in the Black Hills of South Dakota and in Connecticut and Massachusetts, but none of these occurrences have yet been worked to supply lithium.

In the last few years there has been a great demand for lithium minerals for use in the manufacture of lithium carbonate. Since most of this substance now in use is made in Germany, nearly all the American mineral has been shipped to that country. The American supply of carbonate is imported from Germany, selling in New York for $4.20 a pound. The chief use of lithium salts is in the preparation of mineral waters.

The production of lithium minerals in the United States in 1908 amounted to 203 short tons, valued at $1550.

LITHOGRAPHIC STONE

Properties. — Lithographic stone (1, 3) is a very fine-grained, homogeneous limestone, used for lithographic purposes. It may be either pure lime carbonate or magnesian limestone, but so far as known this difference in composition exerts no important influence on its physical character. The two following analyses will serve to indicate this difference in composition, No. 1 being the standard Bavarian stone and No. 2 the Brandenburg, Kentucky, rock: —

	Insoluble in HCl			Soluble in HCl							
	SiO_2	$(AlFe)_2O_3$	CaO	Al_2O_3	FeO	MgO	CaO	Na_2O K_2O	Moist.	H_2O	CO_2
1.	1.15	.22	Trace	.23	.26	.56	53.80	.07	.23	.69	42.69
2.	3.15	.45	.09	.13	.31	6.75	44.76	.13	.41	.47	43.06

The physical character of the stone is of prime importance, for in order to yield the best results it should be fine-grained, homogeneous, free from veins or cracks, of just sufficient porosity to absorb the grease holding the ink, and soft enough to permit its being carved with the engraver's tool. Owing to these strict requirements but few localities have produced good stone.

Sources of Supply. — Lithographic stone is not confined to any one geologic formation, and deposits have been reported from many states both east and west. Some of these appear to be of inferior quality, while others are too far from railroads. The most promising developed deposit is that found at Brandenburg, Kentucky (2, 6), at which locality a bed of blue-gray stone three feet thick is quarried and used by some establishments in the south and southwest. Another bed of good quality has also been described from Iowa (1).

The main source of the world's supply is obtained from the Jurassic limestone of the Solenhofen district in Bavaria (4), in which the quarries have been worked for a number of years, but the supply is said to be becoming unsatisfactory and unreliable. The stones are trimmed at the quarries, and sizes of 22 or 28 by 40 inches are in the greatest demand.

From these they range up to sizes 40 by 60 inches. The best quality stones sell for 22 cents per pound.

The domestic demand is not large, and it is probable that one or two well-developed and well-managed native quarries could no doubt satisfy it.

The successful substitution of zinc or aluminum plates for certain classes of lithographic work is said to have had a noticeable influence on the demand for lithographic stone. Onyx has also, in some cases, been found to make a good substitute.

REFERENCES ON LITHOGRAPHIC STONES

1. Hoen, Ia. Geol. Surv., XIII : 339, 1902. (Ia., also general.) 2. Kübel, Eng. and Min. Jour., LXXII : 668, 1901. (Ky.) 3. Kübel, Min. Resources, U. S. Geol. Surv., 1900 : 869, 1901. (Excellent general article.) 4. Merrill, Nonmetallic Minerals : 146, 1904. 5. Mo. Geol. Surv., Bull. 3 : 38, 1890. (Mo.) 6. Ulrich, Eng. and Min. Jour., LXXIII : 895, 1902. (Ky.)

MAGNESITE

Properties and Occurrence. — This mineral, which is a carbonate of magnesium with 47.6 per cent magnesia (MgO), has a hardness of 3.5 to 4.5 and a specific gravity of 3 to 3.12.

It commonly occurs in veins or in masses replacing other rocks rich in magnesia, such as serpentines, talcose schists, etc.[1] Its color is white or yellowish, and when massive it sometimes resembles unglazed porcelain, but is quite brittle.

Most of the magnesite used in the United States is imported from Styria and Greece, the only important domestic occurrence being California, and although small ones are known in Pennsylvania and Maryland, they are not worked, as they cannot compete with the imported magnesite.

California (1). — Deposits of magnesite (Fig. 94) are scattered along the Coast Range from Mendocino County at least to a point south of Los Angeles, and along the western slope of the Sierra Nevada from Placer County to Kern County. The greatest production comes from near Porterville in Tulare County (Fig. 94). The deposits all occur as veins in serpentine, the larger number being in the Coast Range.

The much-fractured and faulted serpentines of the Coast Ranges, which are probably of Lower Cretaceous age, appear to have been derived from olivine-pyroxene rocks, and the magnesite may have

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[1] The deposits of Quebec, Can., form an interesting exception, being probably of sedimentary character.

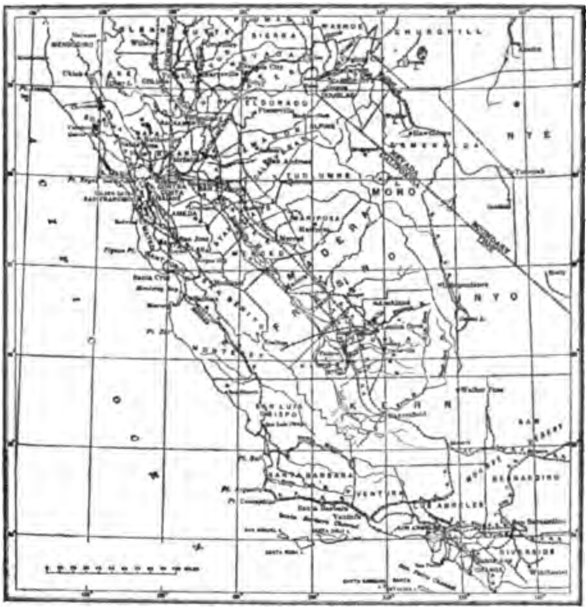

FIG. 94. — Map of California, showing distribution of magnesite deposits. (*After Hess, U. S. Geol. Surv., Bull.* 355.)

been formed from both the serpentine-making minerals and the serpentine itself. It originated probably by the breaking down of the latter by water charged with CO_2, which united with the MgO to form magnesium carbonate. This magnesite was then precipitated in veins, while the silica was removed and often deposited as opal or

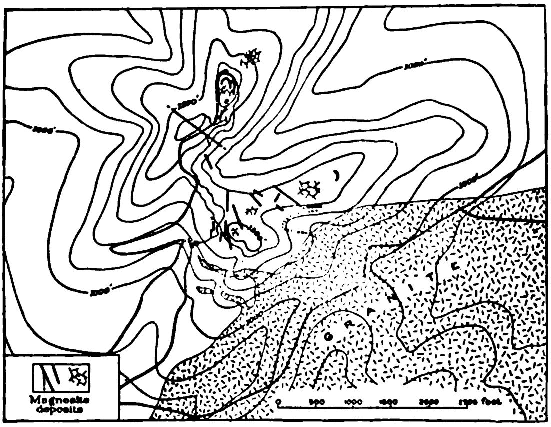

FIG. 95. — Plan of magnesite veins and workings 4 miles northeast of Porterville, Calif. (*After Hess, U. S. Geol. Surv., Bull.* 355.)

quartz in other veins, or with the magnesite. In some cases the magnesite forms a network of veins in the serpentine, but since its origin is due to the action of surface waters, the deposits may be of limited depth. As the magnesite weathers less readily than the serpentine, the vein outcrops often stand out in bold relief.

The following analyses show the composition of the magnesite from several localities:—

ANALYSES OF MAGNESITE

	1	2	3	4	5
SiO_2	7.67	.73	2.28	1.67	2.24
Al_2O_3	.26	.14	.03	3.47	2.05
Fe_2O_3	.29	.21	.26	4.68	
CaO	.04	.40	1.32	2.94	2.48
MgO	43.42	46.61	45.17	86.90	93.63
CO_2	48.08	51.52	50.74		
	99.76	99.61	99.80	99.66	100.40

1. Siliceous Magnesite, 8 m. north of Cazadero, Sonoma County. 2. Alameda claim, Santa Clara County. 3. Four miles northeast of Porterville, Tulare County. Too high in lime for good cement. Used in wood-pulp whitening. 4. Calcined magnesite, Nyustya, Hungary. 5. Calcined magnesite, Greece. 1–5 from Ref. 1.

Uses. — The chief use of magnesite is for the manufacture of refractory bricks. These are produced at several works in Pennsylvania, but only imported material is used, the low price of six to seven dollars per ton making California magnesite profitable only for local markets. The main use of this western magnesite is for making carbon dioxide,[1] while the residue is changed to sulphite and used in paper manufacture. Magnesite is used as a toilet preparation, or in medicine, and as a boiler covering when mixed with asbestos. A moistened mixture of magnesia and magnesium chloride forms a strong cement known as *oxychloride cement.* The metal magnesium is not obtained from magnesite, but from magnesium chloride obtained from the Stassfurt, Germany, and other brines.

The domestic production is obtained entirely from California and has been as follows:—

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[1] Owing to the lower temperature of decarbonation of magnesite it is preferred to calcium carbonate for CO_2 manufacture.

PLATE XXVIII

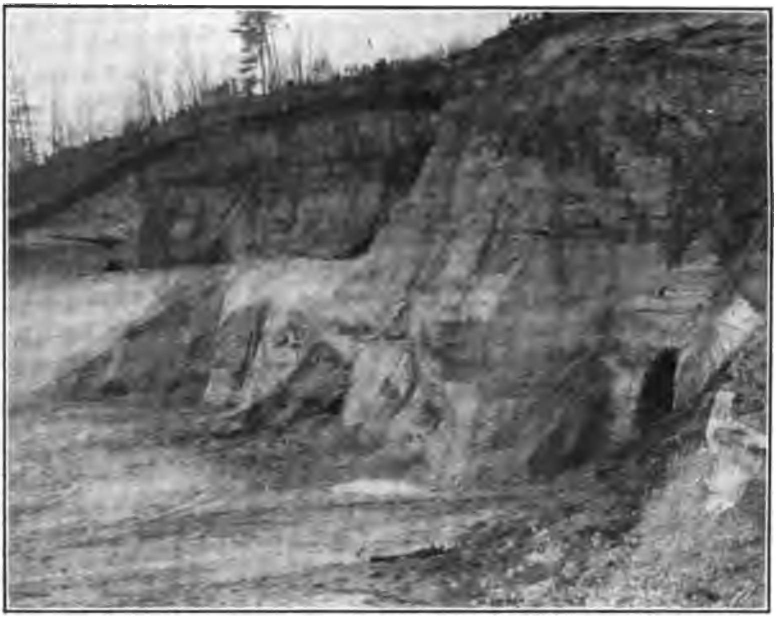

FIG. 1. — View in glass sand pit, on Severn River, Md. — The tunnel shows position of bed of glass sand. The overlying beds carry too much iron oxide. (*H. Ries, photo.*)

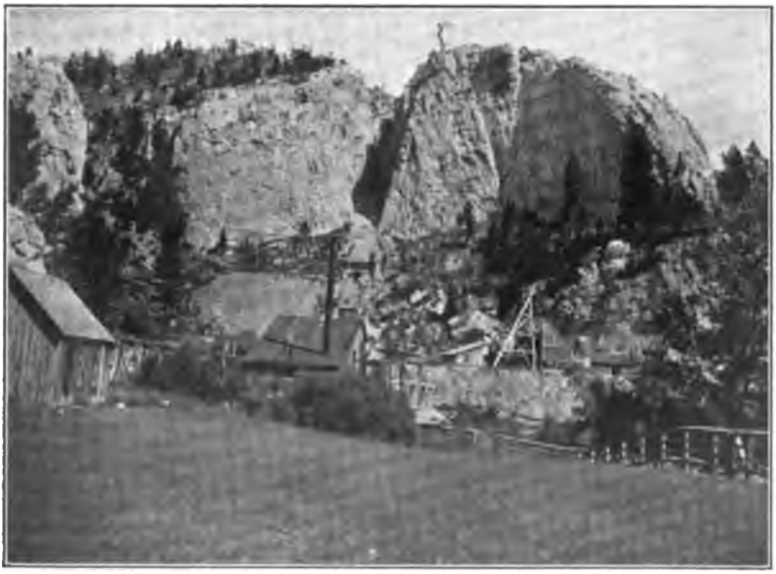

FIG. 2. — View showing sapphire workings, Yogo Gulch, Mont. (*Photo by J. P. Rowe.*) The cut indicates position of sapphire-bearing dike.

Production of Magnesite in United States, 1906–1908

Year	Quantity	Value
	Short Tons	
1906	7,805	$23,415
1907	7,561	22,683
1908	6,587	19,761

REFERENCES ON MAGNESITE

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MEERSCHAUM

Meerschaum or *Sepiolite,* which is well known on account of its use for making pipes, and other smoker's articles, has for many years been obtained mainly from Asia Minor, although other occurrences are known. Recently, however, deposits of promising character have been located in Grant County, New Mexico, and although not yet commercially developed, deserve mention.

Sepiolite has a probable composition of $H^4Mg_2Si_3O_{10}$, and when pure is a white, porous mineral, with a specific gravity of about 2. It absorbs water readily, becoming somewhat plastic, but hardens again on drying. It has a hardness of 2 to 2.5, great toughness, and earthy or conchoidal fracture, the toughness being most pronounced in those forms having a leathery or fibrous texture. Its peculiar physical properties make it of great value for carving into pipes.

In New Mexico two localities are known, both of which lie in the upper Gila River valley, at points located respectively 23 miles east of north, and 12 miles northwest of Silver City.

At the Dorsey mine, northwest of Silver City, the meerschaum occurs as veins, lenses, seams, and balls in a limestone of probable Ordovician age. The veins are filled with chert, quartz, calcite, clay, and meerschaum, and the chert which is the most important gangue mineral, occurs in the veins with meerschaum in bands, lenses, and nodules.

The meerschaum itself occurs either as irregular nodules, or in massive form. Both kinds are tough, but the latter is finer grained, less leathery, and heavier.

The three following analyses represent, (1) the Dorsey mine product; (2) the theoretic composition of meerschaum; and (3) a material from another deposit, which resembles the true meerschaum, but differs from it in its high alumina content.

ANALYSES OF MEERSCHAUM

	1	2	3
SiO_2	57.10	60.8	60.97
Al_2O_3	.58	——	
Fe_2O_3	tr.	——	9.71
MgO	27.16	27.1	10.00
CaO	.17	——	.22
CO_2	.32	——	——
H_2O	14.78	12.1	19.14
Total	100.11	100.0	100.04

The deposit cannot as yet be regarded as a commercial proposition, but may become so.

REFERENCES ON MEERSCHAUM

1. Collins, Min. Wld., XXVI : 688, 1907. (N. Mex.) 2. Sterrett, U. S. Geol. Surv., Bull. 340 : 1908. (General and N. Mex.)

MICA

Properties and Occurrence. — There are few minerals more widely distributed in crystalline rocks than mica, and yet deposits of economic value are rare because the mica flakes are either too small, or too intimately mixed with other minerals for profitable extraction. Only two of the several known varieties of mica, muscovite ($H_2KAl_3Si_3O_{12}$) and phlogopite ($H_6K_6Mg_7Al_2(SiO_4)_7$), are of economic value, the former only being found in deposits of economic value, in the United States. The commercial deposits are usually found in pegmatites, cutting granites, gneisses, and schists. In these the mica is associated with quartz and feldspar (usually orthoclase or microcline, more rarely plagioclase), being found in rough crystals called blocks or *books*, and which are either irregularly distributed through the vein or collected near its sides.

In addition to the quartz and feldspar, other minerals such as tourmaline, beryl, zircon, columbite, samarskite, uranium minerals, garnet, etc., are sometimes present. The pegmatite, which carries the mica, and may be of igneous or gas-aqueous origin, occurs as lenses, veins, irregular masses, etc., of varying thickness and length.

The value of the deposit depends more on the abundance and quality of the mica than the size of pegmatite body.

The best mica is obtained from the more coarsely crystalline rocks; but the widest veins do not necessarily contain the largest blocks. As a rule the mica does not form more than 10 per cent of the vein, and usually not more than 10 or 15 per cent of that mined can be cut into plates, the rest being classed as scrap mica.

There has been some discussion as to whether the pegmatites are true igneous dikes or veins, but the matter cannot be said to be definitely settled in all cases. It is probable that each type of origin is represented.

Distribution in the United States. — Deposits of mica have been worked in a number of states both east and west, and yet but few are steady producers. The more important ones may be described.

North Carolina (4, 9). — The mica mined in this state, which is the leading producer, comes from three belts (Fig. 96); viz., the Cowee-Black Mountain, the Blue Ridge, and the Piedmont belts. That from the first is chiefly clear and of light color ("wine" or "rum"); that from the second is dark smoky brown and often more or less speckled, while that from the third is often of good quality and similar to the Cowee-Black Mountain product. Owing to a frequent capping of residual soil, discovery of the deposits is difficult.

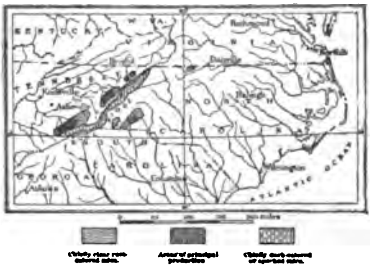

FIG. 96. — Map showing areas in North Carolina in which mica has been mined. (*After Sterrett, U. S. Geol. Surv., Bull.* 315.)

The mica-bearing pegmatites occur in mica, garnet cyanite, hornblende, and granite gneisses and schists, all of Archæan age, the important formations being the Carolina and Roan gneisses. The rocks of these two are interbanded with, and cut by, streaks of granitic or pegmatitic material, the latter forming lenticular bodies or vein-like deposits, which may, or may not be conformable with the schistosity of the country rock.

While they vary in size, 1 to 2 feet seems to be the minimum workable limit for rich and regular "veins." The muscovite, which is the main mica present (biotite being the other), shows a variable mode of occurrence. At one time it is evenly distributed through the pegmatite, at another large crystals are found in clusters scattered through the vein (Fig. 97).

The better grades of North Carolina mica are used for the glazing industry, while the less perfect sheet material is employed for electrical work. The pegmatite veins also carry a number of rare minerals.

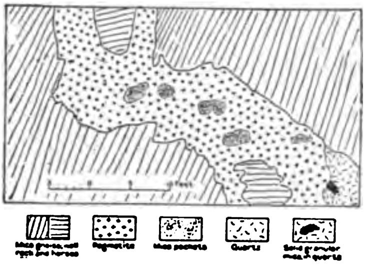

FIG. 97. — Section across pegmatite at Thorn Mountain mine, Macon Co., N. Ca. (*After Sterrett, U. S. Geol. Surv., Bull.* 315.)

South Dakota (8). — Mica is mined in the region around Custer, South Dakota. The muscovite, as is usual, occurs in pegmatite, cutting schists and gneisses, and granite. The material is of evenly granular texture, or shows an irregular segregation of the minerals, with but little banding. This latter is sometimes roughly produced by a segregation of the mica along the walls of the deposit. Very few of the pegmatites around Custer, however, carry enough mica to pay for working them.

In the New York mine (Fig. 98), for example, the rough mica obtained along the walls amounts to 6 or 7 per cent, while the interior portion of the pegmatite carries about 0.5 per cent, and is not worked. The shape of the pegmatite bodies around Custer is variable, but in general they resemble the dike type, and appear to represent an end phase of the granite intrusions of that region, for they not only cut the granite itself, but in places grade into it. Their age is not definitely known.

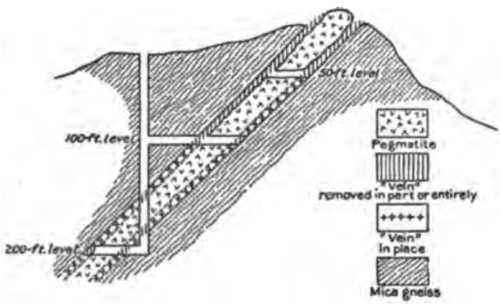

FIG. 98. — Generalized cross section of No. 1 or New York Mine, near Custer, South Dakota. (*After Sterrett, U. S. Geol. Surv., Bull.* 380.)

Other States. — Mica in pegmatite has been worked at Mica Hill, 4 miles northwest of Cañon City, Colorado, and 6 miles north of Texas Creek. That obtained at the former locality is peculiarly adapted to grinding purposes (10). The Virginia (12) occurrences, especially those in Amelia County, are of some importance. That found near Amelia Court House occurs in pegmatite dikes, which intersect the biotite gneiss of the district. The largest dikes are more than 50 feet wide, and the mica occurs in them as thick, highly cleavable blocks, and masses of varying size. Deposits are also known to occur in northwest Georgia (7), and while they resemble the North Carolina deposits, they have not been worked much.

Uses of Mica. — The chief use of mica is for electrical purposes, it being employed as an insulating material in dynamos, motors, high voltage induction apparatus, switchboards, lamp sockets, etc. The domestic product is found to be uniformly satisfactory for electrical work, except for insulation between the copper bars of commutator segments. This use seems to be best served by the amber or phlogopite mica obtained in Canada and Ceylon. The superiority of this variety is due to its easier wearing qualities, which cause it to wear down even with the copper segments. *Micanite* or mica board is sheet mica obtained by cementing small clear pieces of scrap mica together under pressure. Since it can be bent, rolled, and punched, it is utilized mostly for the same purposes as sheet mica. The use of mica for stove doors and chimneys is decreasing, although the glazing industry still demands a considerable amount of the finest grades of sheet mica. Scrap mica is ground for use in the manufacture of wall papers, lubricants, fancy paints, and *micanite.* That used for electrical work must be free from metallic minerals, and that for wall paper and paints must have sufficient luster.

Production of Mica. — The quantity and value of mica produced in the United States from 1904 to 1908 by kinds is given below. The complete production by states is not given by the United States Geological Survey.

PRODUCTION OF MICA IN THE UNITED STATES FROM 1904 TO 1908

YEAR	SHEET MICA		SCRAP MICA		TOTAL VALUE
	Quantity	Value	Quantity	Value	
	Pounds		*Short Tons*		
1904	668,358	$109,462	1,096	$10,854	$120,316
1905	924,875	160,732	1,126	17,856	178,588
1906	1,423,100	252,248	1,489	22,742	274,990
1907	1,060,182	349,311	3,025	42,800	392,111
1908	972,964	234,021	2,417	33,904	267,925

Examination of the statistics since 1880 shows a strong fluctuation in the total value of production.

The average price of sheet mica in the United States in 1908 was 24.1 cents per pound, as compared with 33 cents in 1907 and 17.7 cents in 1906. The average prices for the individual states vary greatly from year to year, due in part to variation between proportion of rough and trimmed mica, and size of sheets produced. The prices per pound of several sizes of selected mica in New York in 1908 were as follows:

2 × 2 in., $0.87; 2 × 3 in., $1.10; 2 × 5 in., $1.70; 3 × 3 in., $2.75; 3 × 4 in., $3.25; 4 × 6 in., $4.75; 6 × 8 in., $6.75.

The imports of mica are given for the last five years, since to state those of one year would not clearly show the fluctuations. The remarkable drop in 1908 is not explained.

MICA IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES, 1903–1908, IN POUNDS

YEAR	UNMANUFACTURED		CUT OR TRIMMED		TOTAL	
	Quantity	Value	Quantity	Value	Quantity	Value
1904	1,085,343	$241,051	61,986	$22,663	1,147,329	$263,714
1905	1,506,382	352,475	88,188	51,281	1,594,570	403,756
1906	2,984,719	983,981	82,019	58,627	3,066,738	1,042,608
1907	2,226,460	848,098	112,230	77,161	2,338,690	925,259
1908	497,332	224,456	51,041	41,602	548,373	266,058

A small quantity of mica is exported each year.

REFERENCES ON MICA

1. Ball, U. S. Geol. Surv., 315 : 423, 1907. (Wyo.) 2. Cirkel, Mica, Its Occurrence, Exploitation and Uses. Dept. Inter., Mines Branch, Can., 1905. (Can. and general.) 3. Colles, Mica and the Mica Industry, New York, 1906. (General.) 4. Holmes, U. S. Geol. Surv., 20th Ann. Rept., VI:691, 1899. (U. S.) 5. Hoskins, Min. Indus., X : 458, 1902. (N. H.) 6. Pratt, Mineral Census, 1902, Mines and Quarries : 1031, 1904. (General.) 7. Sterrett, U. S. Geol. Surv., Min. Res., 1908. (Ga.) 8. Sterrett, U. S. Geol. Surv., Bull. 380 : 382, 1909. (S. Dak.) 9. Sterrett, U. S. Geol. Surv., Bull. 315 : 400, 1907. (N. Ca.) 10. Sterrett, U. S. Geol. Surv., Min. Res., 1908. (Colo.) 11. Sloan, S. Ca. Geol. Surv., Ser. IV, Bull. 2 : 142, 1908. (S. Ca.) 12. Watson, Min. Res. Va., 1907 : 278. (Va.)

MINERAL PAINTS

Under this head are included a number of mineral substances which are used in the manufacture of paints. Some of these can be used directly after cleaning and grinding, while others are roasted to give the desired color.

The substances used and considered in this chapter include ocher, umber, sienna, hematite, siderite, ground slate, and shale. Other substances used in the paint trade, but mentioned elsewhere, are asbestos (p. 211), asphalt (p. 85), barite (p. 217), clay (p. 124), graphite (p. 241), gypsum (p. 178), magnesite (p. 248), pyrite (p. 281), silica (p. 274), talc (p. 286), and whiting.

Hematite. — Certain kinds of hematite, such as the Clinton ore (see Iron Ores), are ground and sold under the name of metallic paints, and much used for coating wooden surfaces and coloring mortar. The ores are sometimes roasted before grinding to improve their color and durability. Although hematite deposits are widespread, and sometimes of large size, the quantity of material showing the necessary uniformity of color, freedom from grit, etc., required for mineral paint is small. Much crude material is supplied by the Clinton ore mines at Clinton and Ontario, New York (8).

At some localities in northwest Georgia and southeast Tennessee the Clinton oölitic hematite occurs in beds too thin to be now mined for iron ore, but its softness, high percentage of iron oxide and color make it available for red paint (3).

The following analyses show the composition of this material.

	I	II	III
Fe_2O_3	72.86	83.14	80.00
SiO_2	21.00	11.90	16.45
P	.40		.28
Mn	.30		

I. Estelle, Ga. II. Ooltewah, Tenn. III. Hinch's Switch, Tenn.

Ochers. — The term ocher, as commonly used, includes the earthy and pulverulent forms of the minerals hematite and limonite. More or less clayey matter is usually present.

Properties and Occurrence. — The ochers show a variety of colors, depending mainly on the chemical composition. Thus hematites give a deep red color, while limonites have some shades of yellow or brown, but whatever the color, uniformity of tint is necessary. Ochers may contain as much as 50 to 75 per cent iron oxide (10). Brown ocher or umber is colored by manganese, and sienna is a yellowish-brown variety.

Ochers may result from (5, 10): the leaching action of percolating waters and subsequent deposition; as residual products, formed by the removal or solution of the soluble parts of the original rock, leaving the insoluble portions, clay and iron oxide, to form the different ocherous colored clays; from the decomposition of rocks rich in iron-bearing silicates; by oxidation of beds of pyrite; by alteration or decomposition of hematite beds; by alteration of more compact forms of limonite; by replacement; by sedimentation.

Distribution of Ocher. — Georgia and Pennsylvania are the largest producers of ocher, but California, Vermont, and other states help to swell the total.

Georgia (5, 6, 10). — In this state the ocher deposits occur in a north-south belt, 8 miles long, lying east and southeast of Cartersville. The ocher is limited to the Weisner (Cambrian) quartzite, in which it occupies an extensively shattered zone of similar position to that of the residual clay derived from the rock decay (Fig. 99). The following analyses represent its composition.

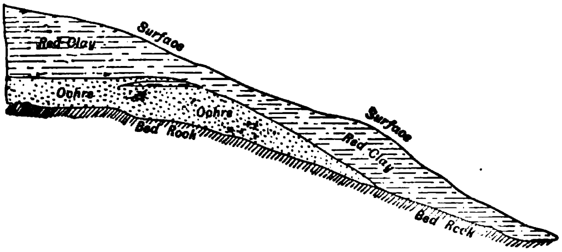

FIG. 99. — Section showing relations of ocher, quartzite, and clay, near Cartersville, Ga. (*After Watson, Ga. Geol. Surv., Bull.* 13.)

ANALYSES OF GEORGIA OCHER

	I	II	III
Fe_2O_3	72.29	56.29	61.40
Al_2O_3	5.55	10.15	7.14
FeO	.46	.39	
MnO_2	.87	.54	2.00
SiO_2 (free sand)	6.65	8.94	11.89
SiO_2(conb)	3.98	9.49	5.84
Moist	.55	2.08	.46
H_2O above 105° C.	9.22	11.34	9.37
	99.57	99.22	98.10

I. Crude ocher, Mansfield Bros., Lot. 462, 4th dist., 3d sec. Bartow Co. II. Crude ocher near Emerson, Bartow Co. III. Refined ocher, Blue Ridge Ocher Co.

The average percentage of limonite in a number of analyses was 74.15 per cent for both the crude and refined ocher. There is admixed with it about 20 per cent of clay and finely divided quartz which cleansing will not eliminate. The ocher of this district ranges from a dark to a light yellow color dependent chiefly on the amount of admixed clay.

According to Watson (10), the Bartow County ocher deposits have been formed by molecular replacement of the quartzite, and subsequent weathering has resulted in the ocher bodies being inclosed in many cases in residual clays derived from the decay of the original rock. Hayes (5) states that the ocher forms a series of irregular branching veins, extending in all directions, but often expanding into bodies of considerable size.

It is believed by Watson (10) that the iron oxide of the ocher was derived largely from the decay of surface rocks and carried downward by surface waters in the form of soluble ferrous salts, but that some was possibly contributed by pyrite in the quartzite. The deposition may have been due to the carbon-dioxide solution of ferrous carbonate meeting an oxidizing solution, resulting in a precipitation of the iron and a solution of the silica of the quartzite.[1]

The main use of the Georgia yellow ocher is in the manufacture of linoleum and oilcloths, especially in England and Scotland. It is employed to a limited extent for paint manufacture.

Pennsylvania. — The ocher deposits of eastern Pennsylvania include the residual deposits of the Reading-Allentown district and the bedded deposits of the Moosehead district. The first named includes the principal ocher belt of Pennsylvania and lies in Berks and Lehigh counties, where the ocher deposits occur as irregular masses in a residual clay derived from the Shenandoah (Cambro-Silurian) limestone. Associated with the ochers are nodules and geodes of limonite, as well as smaller quantities of turgite, ilmenite, siderite, and pyrite. The product after washing, drying, and grinding contains from 12 to 30 per cent Fe_2O_3.

In the Moosehead area a bed of soft, buff-colored shale, found at the base of the Mauch Chunk shale, and resting on the Pocono sandstone (Lower Carboniferous), is mined for paint. It is of low grade, and the product carries from 6 to 7 per cent ferric oxide.

Umber and sienna have been produced in small quantities in

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[1] Van Hise, Treatise on Metamorphism, p. 417.

Illinois and Pennsylvania, and sienna in addition has been obtained from New York.

Siderite (1). — In Southern Carbon County, Pa., there occurs a somewhat extensive but not very thick bed of siderite lying between the Oriskany (Devonian) and Hamilton (Devonian) formations. The section shows

Cement rock	25 feet
Paint "ore"	2 feet
Clay	8 feet
	35 feet

The brown paint "ore," which consists chiefly of iron carbonate, varies in thickness, often between 1 and 2½ feet, and rarely reaching 4 feet. It is in places changed to limonite at the surface, and grows leaner with depth, leading to the belief that it represents a replacement of limestone by surface waters.

Below are given (I) an analysis of the crude ore (7), and (II) an analysis of the roasted product (4).

Analyses of Siderite Paint "Ore" from Pennsylvania

	I		II
Fe	34.60	Fe_2O_3	42.70
Mn	.929	MnO	1.40
SiO_2	16.21	SiO_2	37.20
Al_2O_3	5.492	Al_2O_3	9.40
CaO	3.51	CaO	1.70
MgO	1.081	MgO	1.70
S	.674	SO_3	1.88
P	.018	P_2O_5	.14
Loss on roasting	24.35	H_2O	.60
		CO_2	2.60
	86.854		99.32

This paint is used mainly for freight cars, and in lesser amounts for painting steel, tin, boats, and as a filling in oilcloth and linoleum.

Slate and Shale. — The refuse from slate quarries is sometimes ground and sold as a pigment, and in some localities shales of the proper color and texture are utilized for the same purpose. Their value depends on their color, fineness, and amount of oil required in mixing.

Pennsylvania and New Jersey are the chief producers. The Hamilton (Devonian) shales have been worked for some years in Cattaraugus

County, N. Y., and a product known as *mineral black* is made from the slates of the Hudson River (Ordovician) series.

Gypsum,[1] known also as terra alba or mineral white, is used to some extent as a pigment for printing wall paper.

Barite,[1] or barium sulphate, which is used as an adulterant of white lead, is purified after mining by grinding and washing.

Asbestos[1] is used to some extent in paint manufacture for the so-called non-inflammable or fireproof paints, but the total quantity thus utilized is small.

Graphite,[1] either natural or artificial, supplies a black pigment of permanent color which, on account of its resistance to the atmosphere and ordinary chemicals, is of much value for coating oxidizable metals, such as iron and steel.

Calcium Carbonate, in the form of chalk, known commercially as whiting or paris white, is used as a pigment to alter the shade of other pigments as a basis for whitewash.

Other Paints. — Paints sometimes classed as mineral paints are made from other crude minerals, as follows : zinc white from zinc ore; white lead, red lead, and orange mineral from lead; venetian red from iron sulphate; vermilion or artificial cinnabar from quicksilver; chrome yellow from chromite; cobalt blue from cobaltite.

Production of Mineral Paints. — The production of mineral paints, as well as the imports, are given below.

PRODUCTION OF NATURAL MINERAL PIGMENTS, 1904–1908, IN SHORT TONS

KIND	1904		1905		1906		1907		1908	
	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE
Ocher	16,826	$110,602	13,402	$126,351	15,482	$148,049	16,971	$164,742	17,019	$156,360
Umber Sienna	522	12,960	689	17,004	657	17,394	730	19,309	2,756	70,996
Metallic paint	19,357	204,377	16,489[2]	176,722	17,992	204,026	16,225	195,176	16,224	182,007
Mortar colors	7,525	84,426	10,494	120,430	10,309	111,720	10,490	110,719	9,026	86,961
Slate and shale ground	5,370	53,709	5,181	44,108	5,481	40,540	4,130	40,540	4,828	40,220
Total	49,600	$466,074	46,255	$484,615	49,921	$521,729	48,546	$530,486	49,853	$536,544

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[1] For mode of occurrence and distribution, see main treatment of these minerals on other pages.

[2] Includes a small quantity of unground material.

The imports in 1907 and 1908 were as follows: —

	1907		1908	
	Quantity	Value	Quantity	Value
	Pounds		*Pounds*	
Ocher	11,991,971	$104,585	9,253,760	$75,076
Umber	3,398,259	26,713	2,406,709	20,264
Sienna	2,191,195	35,616	1,763,894	28,865

France is the largest producer of ocher, the United States being second.

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MONAZITE

Properties and Occurrence. — This mineral is an anhydrous phosphate of the rare earth metals, cerium, lanthanum, praseodymium and neodymium; but its economic value is due chiefly to the small amount of thoria which it contains. ' The percentage of thoria in monazite ranges from less than 1 to 20 or more, and in commercial monazite varies between 3 and 9 per cent. Although grains of monazite are found scattered through many granites and gneisses, still no occurrences of this type have thus far proven to be of commercial value. The economically valuable deposits are all found in stream gravels, derived from the disintegration of monazite-bearing rocks. Monazite is usually light yellow to honey yellow, red, or brown in color, has a resinous luster, a specific gravity of 5.203 (Penfield and Sperry) and a hardness of 5 to 5.5. It is very brittle. Its gravity and color aid in its ready determination.

In the United States deposits of monazite sand have been found in the granite and gneiss areas of North Carolina (2, 4) and South Carolina (3), and these, together with deposits found in Brazil (1), supply nearly the entire world's demand. A small quantity is also obtained from southern Norway, as a by-product in feldspar mining. The following analyses indicate the composition of monazite: —

ANALYSES OF NORTH CAROLINA MONAZITE

	P_2O_5	Ce_2O_3	La_2O_3	ThO_2	SiO_2	H_2O
Burke Co., N. C. . . .	29.28	31.28	30.88	6.49	1.40	.20
Alexander Co., N. C. .	29.32	37.26	31.60	1.48	.32	.17

The deposits known in the Carolinas have been found within an area of about 3500 square miles (Fig. 100), which lies wholly within the Piedmont Plateau region. The chief rocks are gneisses of different kinds, schists, granite, pegmatite, peridotite, quartz-diorite, and diabase, but the structural conditions are complex, and metamorphism has often obscured the original character of the rocks. The latter are, moreover, often concealed by a heavy mantle of residual soil.

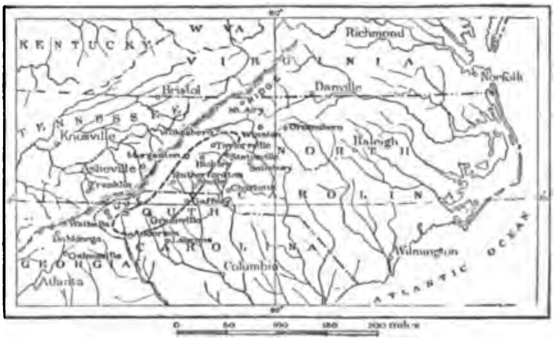

FIG. 100. — Map showing area of monazite deposits of known commercial value in southern Appalachian region. (*After Sterrett, U. S. Geol. Surv., Bull.* 340.)

Where the monazite has been found in the bed rock, it has been chiefly in a porphyritic pegmatized gneiss. In the ordinary gneiss, and in the highly pegmatized gneiss; the monazite is far less abundant. These occurrences in bed rock have not, however, proved to be of commercial value, and the only important deposits are the placers, and gravel beds in the streams and bottom lands, as well as some surface soils, adjoining the rich gravel deposits.

In some areas the saprolite or rotted rock underlying gravel deposits has been washed with favorable results.

The monazite-bearing gravels range in thickness from one to two feet, including overburden, up to 6 to 8 or more feet, and the monazite on account of its gravity has collected more abundantly in the lower portion. The deposits are richest in those regions containing an abundance of granitic rocks, pegmatized gneisses, and schists, while in the gravel itself, the presence of considerable quartz débris, and fragments of such rocks as pegmatite, granite, mica, and cyanite gneiss, are favorable signs.

In some cases the supply of monazite in the stream gravels may be replenished by wash from the hillsides which are underlain by residual soils containing monazite grains.

The monazite found in the pegmatized gneiss is believed to have been derived from aqueo-igneous solutions passing through the rock, and depositing and recrystallizing portions of it into the minerals of pegmatite.

Uses. — Monazite is usually separated from the gravels by a washing process, and in addition magnetic separation has in some cases been employed to separate it from the associated garnet, magnetite, and quartz.

The value of monazite lies in the incandescent properties of the oxides of the rare earths, cerium, lanthanum, didymium, and thorium, which it contains, and which are utilized in the manufacture of mantles for incandescent lights.

Production of Monazite. — The production of monazite for several years was as follows: —

PRODUCTION OF MONAZITE IN THE UNITED STATES FROM 1905 TO 1908

YEAR	QUANTITY CONCENTRATES	VALUE
	Pounds	
1905	1,352,418	$163,908
1906	847,275	152,560
1907	548,152	65,800
1908	422,646	50,718

The 1907 production includes a small quantity of zircon; the 1905 production includes small quantities of zircon and columbite. The imports of thorium nitrate in 1908 were 65,289 pounds, valued at $173,239.

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CHAPTER XII

MINOR MINERALS — PRECIOUS STONES — WAVELLITE

PRECIOUS STONES

THE names *gems* and *precious stones* (1, 2) are applied to certain minerals, which on account of their rarity, as well as hardness, color, and luster, are much prized for ornamental use. The hardness is of importance as influencing their durability, while their color, luster, and even transparency affect their beauty. A distinction is some times made between the more valuable stones, or gems (such as diamond, ruby, sapphire, and emerald), and the less valuable, or precious stones (such as amethyst, rock crystal, garnet, topaz, moonstone, opal, etc.).

Most gems are found in unconsolidated surface deposits representing either residual material or alluvium derived from it, and in the latter their concentration and preservation is due to their weight and hardness. When found in solid rock, the metamorphic and igneous types are more often the source than the sedimentary ones.

Many different minerals are used as gems (1, 2), but only a few of the important ones can be mentioned here, and the number of the more valuable kinds found in the United States is very limited (4, 12). Every year, however, discoveries of one kind or another are reported, and reference is usually made to these in the Mineral Resources of the United States published annually by the United States Geological Survey.

Diamond. — This mineral, which is the hardest of all known natural substances, is pure carbon, crystallizes in the isometric system, and has a specific gravity of 3.525. It occurs in many different colors, of which white is the commonest, and is found either in basic igneous rocks or in alluvial gravels.

The massive forms, known as *bort* or *carbonado*, have little or no cleavage, and are of value only as an abrasive.

The greatest number of diamonds come from South Africa, but other deposits of commercial value occur in India, Borneo, and Brazil.

In the United States a few scattered diamonds have been found in the drift or soil of the southern Alleghanies, California, Wisconsin, and Indiana, but they are all small (10, 12, 13, 15).

The only and first locality in North America where diamonds have been found in place, is in Pike County, Ark. (9, 13), where, at a locality 2½ miles southeast of Murfreesboro, there is a small area of peridotite. This igneous rock forms a small stock which has cut through indistinctly bedded Carboniferous sandstones and quartzites, which are overlain unconformably by Cretaceous sandstones, and the latter in turn by post-Tertiary conglomerates.

The residual clay derived from the peridotite is of two kinds, the one of yellowish-green color representing more advanced decomposition, and the other of bluish-green shade and usually underlying the first. The bluish-green material is known to extend to a depth of from 20 to 60 feet. The diamonds are found disseminated through the decomposed peridotite.

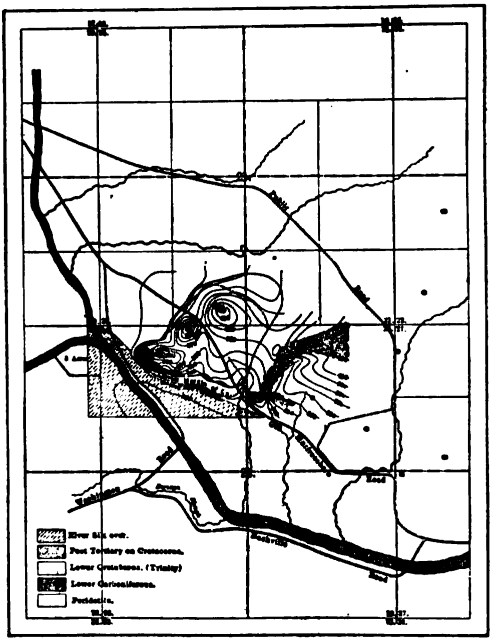

FIG. 101. — Map of the Arkansas diamond area. (*After Fuller, Eng. and Min. Jour., LXXXVII.*)

Up to July 1, 1909, over 700 diamonds had been found. Of the first 540 stones discovered (9), 505 weighed 217 carats. The largest one found weighs 6½ carats. Three have been cut and yielded gems valued at from $60 to $175 per carat.

More recently a new peridotite area has been described, which is located three miles south of east of Murfreesboro. This has also yielded a few diamonds (21).

The probable origin of the diamond has provoked much discussion among scientists, and a number of successful attempts have been made to produce it artificially. These indicate its formation by crystallization from a fused magma, which in most cases has a composition resembling peridotite. As corroborative of this we have the occurrence of South African diamonds in or near volcanic pipes of peridotitic character, and Lewis has suggested that the stones were formed by the solvent action of the molten peridotite magma on carbonaceous shales. Some have disputed this idea, and believe that the diamond is an original constituent of the magma, from which it crystallized on cooling. As opposed to an igneous origin is the statement of G. F. Williams, that he found an inclusion of apophyllite (a highly hydrous mineral) in a Kimberly diamond. All diamonds do not occur in peridotite, for in Brazil hydromica schists and quartzite may contain them, while certain Indian ones appear to have been derived from pegmatite, and some Australian ones in hornblende-diabase.

The most that can perhaps be said is that, while much of the evidence indicates an igneous origin, the diamond has not necessarily been obtained in all cases from the same kind of magma.

Emerald. — This gem is a variety of beryl, essentially a glucinum-aluminum silicate. Its hardness is 7.5 to 8, and its specific gravity 2.5 to 2.7. Its brilliant green color is attributed by some to chromium, by others to organic matter. Brazil, Hindustan, Ceylon, and Siberia are all important sources. In the United States a few have been found in western North Carolina (12, 15) in gravel deposits. Flawless emeralds are very rare, and equal in value to diamonds.

Aquamarine and *oriental cat's-eye* are also varieties of beryl. *Brazilian emerald* is a green variety of tourmaline, and *lithia emerald* an emerald-green spodumene.

Garnet. — Of the several varieties of garnet, three are well known as gem stones, viz. the precious garnet, or almandite, Bohemian garnet, or pyrope, and manganese garnet, or spessarite. The first two are of deep crimson, the last of orange-red or light red-brown color. India is the main source of supply. All three varieties mentioned are found in the United States, but there is a regular production only of the pyrope from Arizona and New Mexico, and a purple-red garnet known as rhodolite from North Carolina (4, 12, 15).

Those found in the southwest (22) have for many years been collected by the Navajo Indians. Clear red garnets associated with peridot gems, which have been weathered out of basic igneous rocks, have been found at several places around and north of Fort Defiance, Utah, but those obtained from these localities are small and not worth cutting. The supply of gem garnets comes from close to the Utah-Arizona line, at a point 12 miles southwest of the junction of the Chin See Valley and San Juan River in Utah. In this region, which is underlain by sandstone of probable Triassic age, pierced by numerous basic igneous rocks, the garnets are found chiefly in a coarse, unconsolidated drift or gravel layer, associated with feldspar, diopside, quartz, and igneous rock fragments. The garnets range in size from small grains to others over 3 centimeters in diameter, but the gem stones are not over 12 millimeters across.

Opal, which is hydrous silica chemically, is amorphous, with conchoidal fracture, yellow, red, green, or blue color, and often showing considerable iridescence. The varieties recognized are the precious opal, fire opal, girasol, and common opal. The finest examples of precious opal are obtained from Hungary. Others are also found at Queretaro, Mexico, and in Oregon and Washington. The United States production is small, although it is thought that that are many scattered occurrences in the igneous rocks of Washington, Idaho, Oregon, California, Nevada, and Utah (4, 12).

Peridot. — This name is applied to a deep olive-green variety of chrysolite, a silicate of magnesium and iron. Peridot has a low hardness (6.75) as compared with other gems, while its specific gravity, 3.3 to 3.4, is relatively high.

Gem peridot is found in two regions in Arizona (22) viz. north of Forth Defiance in the Navajo Indian Reservation, and near Rice in the White Mountains Apache Indian Reservation. In the former district the peridot is plentiful, and is found associated with volcanic rocks. These are monzonite porphyry, orthoclase basalt, and peridotite agglomerate. The peridot, which appears to have been derived from the agglomerate, is found in the soil, and associated with it are such minerals as garnet, diopside, quartz, calcite, titanic iron, etc. Gems of 1 to 2 carats' weight are fairly abundant, and some of 3 to 4 carats are found. Those of dark yellowish-green color are commonest.

In the Rice district peridot is found not only in the original basalt rock matrix, but also loose in the soil.

Ruby. — A red, transparent variety of corundum (Al_2O_3), having a hardness of 9 and a specific gravity of 4. The most valuable color in ruby is a deep, clear, carmine red. Rubies of large size are scarce, so that a 3-carat stone of good color and flawless is worth several times as much as a diamond of the same size. The best ones come from Burma. In the United States they have been found in the stream gravels of Macon County, North Carolina, but the production is not a steady one. Those found in Arizona and other western states are not true rubies, but a variety of garnet (4, 12, 15).

Sapphire is a blue, transparent variety of corundum (Al_2O_3). It is of slightly greater hardness and specific gravity than the ruby, though of similar composition. Sapphires of good color and size are more common than rubies and cheaper. The best sapphires come from Siam. In the United States they have been found in the gravels of Cowee County, North Carolina, but Yogo Gulch, Montana, is now the main source of domestic supply. They range in weight from under 1 up to 4 or 5 carats (4, 12, 18).

The Montana sapphires were first found in gravel bars on the Missouri River, but subsequently they were discovered in dikes of basic igneous rock cutting Carboniferous (?) limestone in southwestern Fergus County. The rock is of somewhat basic character belonging to a type known as monchiquite, and the sapphires are obtained from the somewhat decomposed portions of the dike.

There are two companies, both operating on the same dike, which has a width of 10 to 20 feet, and has been traced for a distance of 5 to 6 miles.

Spodumene. — A remarkable transparent lilac-colored and pale pink to white spodumene, known as *Kunzite* (14) has been found in California not far from the rubellite locality, and occurring in a pegmatite dike, where it is closely associated with gem tourmalines.

Topaz. — This is a fluosilicate of alumina, crystallizing in the orthorhombic system, with a hardness of 8, specific gravity of 3.5, vitreous luster, and yellow, green, blue, red, or colorless. It occurs in gneiss or granite, as well as in other metamorphic or igneous rocks, and is associated with beryl, mica, tourmaline, etc. It is also found in alluvial deposits. The best gem stones come from Ceylon, the Urals, and Brazil. In the United States they have been found in small quantities in Maine, Colorado, California (12), and Utah.

In Utah topaz (17) is found in the Thomas range of mountains about 40 miles north of Sevier Lake, at a locality known as Topaz Mountain. The transparent crystals occur in lithophysæ in rhyolite, and vary from colorless to wine color. Rough opaque crystals are scattered through the solid rhyolite. The crystals are believed to have been formed by vapors or solutions contemporaneous or nearly so with the final consolidation of the rock. In the weathering of the rock the crystals fall out and become mixed with the soil, the colored ones fading on exposure to the light.

Topaz is obtained from pegmatite veins near Ramona, San Diego County, where it occurs in pockets in albite and orthoclase. The topazes are white, yellow, sea-green, and sky-blue, some of them being of large size (14).

Tourmaline. — This is a complex silicate, of aluminum and boron, with usually varying amounts of iron, magnesium, alkalies, and water. It has a hardness of 7 to 7.5 and a specific gravity of 2.98 to 3.20. The color is variable, and this variation may exist in the same crystal.

The opaque, black, or brown tourmaline is a somewhat common mineral in many metamorphic rocks, as well as in granite and other eruptive rocks, but this variety has no value as a gem.

Gem tourmalines are, however, rather rare, being known in Brazil, Russia, and Ceylon, and in this country in the states of Maine, Connecticut, and California. Of the gem tourmalines the red ones are most highly prized, especially the darker ones; the green ones are usually dark green.

A large number of green tourmalines have been obtained from a pegmatite granite at Paris, Maine, and many are found in a belt extending from Auburn to Newry (23). The gems here are likewise found in pegmatite, and are associated with beryl.

An interesting and important occurrence of red tourmaline (*rubellite*) has been worked at Pala, San Diego County, California. The crystals here form radiating groups in lepidolite and the earlier discovered ones were clear enough for cutting. Valuable crystals, many of gem character, have since been found in pegmatite veins near Pala, and near Mesa Grande (14).

Turquoise is a massive hydrated aluminum copper phosphate, of waxy luster, blue to green color, and opaque. Its hardness is 6, and specific gravity 2.75. It usually occurs in streaks and patches in volcanic rocks. The best varieties are obtained from Persia, but it is also obtained from Asia Minor, Turkestan, and Siberia. In the United States turquoises are found in the Los Cerillos Mountains near Santa Fé, New Mexico, and Turquoise Mountain, Arizona, as well as in Colorado.

It is interesting to note that turquoise was hardly known in the United States in 1890, but now the bulk of the world's supply comes from the southwestern states and territories (16 *a*, 22, 25).

In 1908 the production of turquoise in the United States came from New Mexico, Nevada, Arizona, California, and Colorado.

Turquoise mines have been operated in the Burro Mountains, 15 miles southwest of Silver City, New Mexico. The country rock of granite, which is cut by andesite-porphyry, andesite, and dacite, is much altered, and the turquoise is found in a vein or fissured zone, which contains kaolinized feldspar and secondary quartz.

In this strip, which is 40 to 60 feet wide, the turquoise occurs as veins and nuggets, the former filling cracks in the granite $\frac{1}{16}$ to $\frac{3}{4}$ inches wide, and the latter in the kaolin. The veinlets often cross and indicate successive periods of deposition.

A diversity of opinion exists regarding the origin of the turquoise. Silliman (Amer. Jour. Sci., 1881, July, p. 67) believes it to have been formed by heated water and vapors, which destroyed the original character of the rock and produced new compounds. Clarke and Diller suggested that the turquoise represents a replacement of the apatite of the granite. Johnson (16 *a*) advanced the theory that gases played a rôle in the decomposition of the rock, and called attention to the association of fluorite with the turquoise. The alumina of the turquoise, he thinks, was derived from the feldspar, the phosphorus from the apatite, and the copper from cupriferous solutions which formed the ores in that region.

Zalinski (25) believes that hot solutions, coming from below, caused a kaolinization of the granite, the silica set free in this connection being deposited in cracks and fractures with the turquoise. Solutions carrying aluminum phosphate rose along fissures parallel with the walls, while the copper solutions came along an intersecting series. Intermingling of the two solutions formed the turquoise.

In Mohave County, Arizona (22), the turquoise is found in the younger intrusive porphyries and granite, both of which have been more or less altered, especially around the turquoise deposits. This alteration consists of kaolinization, but there has also been some silicification, as shown by a deposition of quartz in joints and between the grains. Some of the turquoise seems to have been derived from the kaolin by the addition of phosphoric acid and copper, but much of it has been deposited from solution, as it occurs as seams and veinlets, as well as in patches or streaks in quartz seams and veinlets. The nodular turquoise is less common.

The Colorado turquoise deposits are associated with trachyte, but they show relations similar to the Arizona material.

Variscite. — This mineral alone is not used as a gem stone, but it is cut with its associated matrix. This mixture, which is sometimes called **amatrice** (26), is composed of variscite, wardite, and probably other associated minerals such as chalcedony and quartz. The first two are hydrous phosphates of aluminum, showing varying shades of green, of compact, tough character, and having a hardness of 4 and 5 respectively. The matrix consists of chalcedony and quartz with other minerals, among them yellowish gray and white phosphates. The decorative value of the material lies in the variety and arrangement of its colors.

PRODUCTION OF PRECIOUS STONES IN THE UNITED STATES IN 1906, 1907, AND 1908

	VALUE			REMARKS ON 1908 PRODUCTION
	1906	1907	1908	
Agates, chalcedony, etc., moonstones, etc., onyx.	$800	$650	$1,125	California, Utah, and Michigan.
Amethyst	700	850	210	Colorado and North Carolina.
Azurmalachite, malachite, etc.	—	250	5,450	4,676 pounds; Arizona and Utah.
Benitoite	—	1,500	3,638	1,048 cut stones, rough material, still unsold.
Beryl, aquamarine, blue, pink, etc.	9,000	6,435	7,485	California, North Carolina, New Hampshire, Maine, and Connecticut; partly cut gems.
Californite	—	25,000[1]	—	Mined but not sold.
Catlinite	—	25	—	No production reported.
Chiastolite	25	20	—	Do.
Chlorastrolite	—	—	25	Michigan.
Chrysocolla	—	150	600	Arizona and California.
Chrysoprase	32,470[1]	46,500[1]	48,225[1]	3,990 pounds; California, in the rough.
Cyanite	—	100	—	No production reported.
Diamond	—	2,800[1]	2,100[1]	362 stones; Arkansas.
Diopside	5	—	120	Utah and California.
Emerald	—	1,320[1]	—	No production reported.
Epidote	—	60	—	Do.
Feldspar, sunstone, amazon stone, etc.	100	1,110	2,850	2,105 pounds; Colorado and North Carolina.
Garnet, hyacinth, pyrope, almandine, rhodolite.	3,000	6,460	13,100	California, Utah, and North Carolina, partly cut gems.
Gold quartz	—	1,000	1,010	Western States and North Carolina.
Jasper	—	675	—	No production reported.
Opal	—	180	50	20 pounds rough; Colorado.
Peridot	2,400	1,300	1,300	Chiefly from Arizona.
Phenacite	250	25	95	Maine, Colorado, and New Hampshire.
Petrified wood	150	325	—	No production reported.
Prase	50	—	—	Do.
Pyrite	—	400	—	Do.
Quartz, rock crystal, smoky quartz, rutilated, etc.	3,050	2,580	3,595	Several hundred pounds in the rough; some cut gems.
Rose quartz	4,000	6,375	568	6,500 pounds in the rough; South Dakota.
Rhodochrosite	—	150	—	No production reported.
Rhodonite	—	—	1,250	500 pounds; California.
Ruby	600	2,000	—	No production reported.
Rutile	—	200	—	Do.
Sapphire	39,100	229,800[1]	58,397[1]	1,655,402 carats; Montana and Indiana.
Smithsonite	—	800	1,200[1]	New Mexico and Utah.
Spodumene, kunzite, hiddenite.	14,000	14,500	6,000[1]	90 pounds; California.
Thompsonite	—	—	35	Michigan.
Topaz	1,550	2,300	4,435	California, Utah, Texas, and Colorado.
Tourmaline	72,500[1]	84,120[1]	90,000[1]	3,300 pounds; California, Connecticut, and Maine.
Turquoise and matrix . .	22,250	23,840	147,950[1]	29,590 pounds; Arizona, New Mexico, Nevada, and California.
Variscite, amatrice, utahlite	2,000	7,500	14,250	Utah, cut gems and in the rough.
	$208,000	$471,300	$415,063	

[1] Estimated.

Production of Precious Stones. — The United States produces a number of different kinds of gems and precious stones, but the total output is by no means large. Moreover, those kinds most used are produced in but small amounts. The collection of accurate statistics of production is, for several reasons, quite difficult, and therefore the output has to be estimated in some cases. The figures of production for 1906 to 1908, together with the producing states in 1908, are given on the opposite page.

The imports of precious stones into the United States for 1904 to 1908 as reported by the Bureau of Statistics is given below.

YEAR	VALUE	YEAR	VALUE
1904	$27,228,963	1907	$31,866,599
1905	36,845,519	1908	13,700,404
1906	43,602,476		

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QUARTZ

Although this material has been briefly referred to under abrasives and glass sands, it is sufficiently important to require treatment as a special topic.

Silicon is the second most abundant constituent of the earth's crust, and quartz, of which it is an important ingredient, is the most abundant of all minerals, but varies greatly in its mode of occurrence and uses. Thus some varieties, such as rose or smoky quartz, amethyst, etc., are used as gems. Quartz in the form of sand is employed for molding (p. 232), building, glass-making (p. 237), and pottery manufacture, etc. In the form of sandstone and quartzite (p. 116) it is of value as a structural material.

The forms of quartz considered here are the massive crystalline quartz (often known as vein quartz), flint, and quartzite used for purposes other than building or paving.

Vein Quartz (1–3). — This form of quartz, which is white, or less often rose or smoky, occurs in veins or dike-like masses, usually in metamorphic rocks. It may be of high purity, or may be mixed with feldspar, mica, etc., as an ingredient of pegmatite, in which case it is obtained as a by-product in the mining of feldspar. Vein quartz is produced in Connecticut, New York, Pennsylvania, and Maryland. A crystalline quartz, not of vein character, obtained in southern Illinois is referred to under Tripoli (p. 290).

Quartzite. — This rock is quarried at a few localities for special purposes. Thus in Cherokee County, North Carolina, a vitreous Cambrian quartzite has been quarried for use as a flux in copper smelting. Large quantities of a hard brittle quartzite have also been quarried near Wausau, Marathon County, Wisconsin, the ground product being used for sandpaper and other abrasive purposes, filters, bird grit, wood filler, etc. It analyzes 99.07 per cent silica.

Flint or Chert. — This term is applied to lusterless quartz of very compact texture and conchoidal fracture, which often forms nodules in limestone or chalk. In some cases these concretions may represent silicified fossils. Flint nodules are found in many formations in the United States, but little of the domestic material has been utilized except for road metal. The entire supply of true flint demanded by this country for special purposes is obtained from France, England, Norway, and even Greenland, being brought over as ballast. The smaller nodules are used in tube mills, but much of the supply is calcined to whiteness and then ground for use in pottery manufacture.

Uses of Quartz. — Quartz is extensively used in pottery manufacture to diminish the shrinkage of the ware in burning, and for this purpose it should have under 1 per cent of iron oxide. In recent years quartzite and sandstone have been more used than vein quartz. It is also employed in the manufacture of wood filler, paints, scouring soaps, sandpaper, filters, and tooth powders. Blocks of massive quartz and quartzite are employed as a filter for acid towers. Quartz is also used as a flux in copper smelting and in the manufacture of silicon and ferrosilicon. Much chemical ware is now made of fused quartz.

Production of Quartz

PRODUCTION OF QUARTZ (EXCLUSIVE OF ABRASIVE QUARTZ) IN THE UNITED STATES, 1904 TO 1908, IN SHORT TONS

YEAR	CRUDE		GROUND		TOTAL	
	Quantity	Value	Quantity	Value	Quantity	Value
1904	41,490	$28,890	10,780	$71,700	52,270	$100,590
1905	39,555	33,409	11,590	70,700	51,145	104,109
1906	41,314	37,632	25,383	205,380	66,697	243,012
1907	5,618	4,282	17,359	152,812	22,977	157,094
1908	23,505	32,443	15,320	106,203	38,825	138,646

The imports of flint and flint stones in 1908 were valued at $219,754 (unground). Pure crystalline quartz, for pottery, paint, and wood filler brings about $2 to $3.50 per long ton, crude, f.o.b. quarries, while the ground product sells for $6.50 to $10 per short ton f.o.b. mills. Quartzite for sandpapers sells for $1 to $2 per long ton f.o.b. mines, and $6 to $8 ground, f.o.b. mills. The finest ground quartz for tooth powders sells for as high as $20 per ton. Imported French flints are quoted at $3.50 to $4 per long ton f.o.b. Philadelphia.

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STRONTIUM

Sources and Occurrence. — The two minerals serving as sources of strontium salts are celestite ($SrSO_4$) and strontianite ($SrCO_3$).

Of these two the former is the more important, but the latter is the more valuable, as the strontium salts can be more easily extracted from it.

Both celestite and strontianite have been found at a number of localities in the United States, but seldom in large quantities. One important deposit of celestite has been found in limestone caves near Put-in Bay, Strontian Island, in Lake Erie, and in opening up the cave 150 tons of the mineral were taken out. Similar occurrences have been found in limestones in other states, but none of them have any commercial value.

Nearly all the strontium salts now used in the United States are imported from Germany, the crude material being obtained in part from Westphalia, Germany, and also from Thuringia, Germany, and Sicily.

Uses. — Strontium salts are used in sugar refining, in fireworks manufacture, and to a small extent in medicine.

REFERENCE ON STRONTIUM

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SULPHUR AND PYRITE

These two minerals are discussed in the same chapter because both serve as sources of sulphur or sulphuric acid.

SULPHUR

Native sulphur may be formed in several different ways as follows:

Solfataric Type. — Sulphur is often found in fissures of lava and tuff around many active and also extinct volcanic vents.[1] When thus formed as a volcanic sublimate it may be a product of reactions between sulphur dioxide and hydrogen sulphide. It may also be formed by incomplete combustion of hydrogen sulphide, probably as follows: $2\,H_2S + O_2 = 2\,H_2O + 2\,S$. This latter change probably occurs at least a short distance below the surface, where oxygen is deficient, as at the surface the H_2S may form H_2SO_4.

Deposits of the solfataric type are rarely of commercial importance, but they are worked in Japan, and have also been worked in the crater of Popocatepetl in Mexico.

Mineral Spring Deposits. — Sulphur is not an uncommon deposit around mineral springs, its deposition being due to imperfect oxidation of hydrogen sulphide. The latter may have originated by action of acid waters upon sulphides, through reduction of sulphates (gypsum, for example) by microörganisms, or in some cases it is possibly of magmatic origin. The hydrogen sulphide is brought up by spring waters, which are not necessarily of magmatic origin.

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[1] Ferric chloride is sometimes deposited around fumarolic vents, and might, owing to its similar color, be at first mistaken for sulphur.

Gypsum Type. — Sulphur is thought to be sometimes formed by the reducing action of bituminous matter on gypsum, in which event it would be found in sedimentary rocks.

The change involved is a reduction of the calcium sulphate of the gypsum to calcium sulphide, with the production also of carbon dioxide and water. The sulphide, then, by reaction with the carbon dioxide of the air and with water, yields calcium carbonate, native sulphur, and hydrogen sulphide.

This type of sulphur is often of great economic value, and deposits are found in a number of countries. Both the Sicilian and Louisiana deposits are thought by some to have originated in this manner, while others have argued for a different derivation. (See Ref. 3, and La. Ref. under Oil.)

It is of interest to note in this connection that gypsum and sulphur might be associated without one having been derived from the other, by reactions between hydrogen sulphide and calcium carbonate (Ref. 3, p. 496).

Whatever the origin of sulphur, it can be said that in sedimentary rocks, the association of limestone, gypsum, sulphur, and hydrogen sulphide is not uncommon.

Metallic Sulphide Type (4). Sulphur may result from alteration of pyrite, marcasite, or related sulphides, possibly through action of bituminous matter. Gypsum is a common associate. No deposits of economic value have been formed in this manner.

Distribution of Sulphur in the United States. — Louisiana and Utah are the most important producers, smaller quantities coming from other western states, especially Wyoming.

Louisiana (4, 5, 10). — The deposits of sulphur found in this state are the most important domestic source of this material. They occur in Calcasieu Parish, and were discovered as early as 1868 in boring for oil and gas at the head of Bayou Choupique, 15 miles west of Lake Charles.

The bed of sulphur, which is of Cretaceous age (Harris and Veatch), lies 300 to 400 feet below the surface, is over 100 feet thick, and is underlain by gypsum and salt. It is supposed by some to have been derived from gypsum, but Harris suggests the possibility of its precipitation from ascending hot waters (see under Salt, p. 161).

Owing to the quicksand-like character of the overlying beds, attempts to sink a shaft to the deposit were unsuccessful. It is now obtained by pumping superheated steam down through pipes, melting the sulphur, and drawing it to the surface, where it is discharged into vats to cool and solidify.

Utah (6). — Sulphur has been mined at Sulphurdale in central Utah more or less continuously for thirty years. In this district there are found a series of rhyolites and andesites, overlain in places by basalts, the whole resting probably on Paleozoic sediments.

The sulphur, which occurs in a soft rhyolitic tuff (sometimes called gypsum), sometimes forms cylindrical masses or cones 10 to 15 feet in diameter, and with a rudely radial structure, but most of it is found as a dark-colored impregnation or cementing substance of the tuff.

Occasionally there are seen branching veins of nearly pure yellow sulphur, with a banding parallel to the walls, and these may represent fissure fillings from solution, since acid water partly filled with yellow sulphur issues from the fissures.

The crude material varies greatly in richness, some showing as much as 80 per cent sulphur, but rock running as low as 15 per cent is marketable. An analysis of the sulphur from the retorts yielded: S, 99.71; nonvolatile matter (SiO_2, Fe_2O_3, etc.), .23; free SO_3, tr.; moisture at 100° C., .06.

A volcanic origin is suggested for the sulphur, because of its close association with volcanics, and the position of the beds along a fault line. Gas now escapes from the deposits in large volumes, and hydrogen sulphide boils up through water standing in the workings. The sulphur may therefore have been precipitated by the oxidation of the hydrogen sulphide, which is presumably of volcanic origin. Oxidation of the sulphur may give SO_3 and this by reaction with water, H_2SO_4. Analysis of water issuing from the beds shows sulphuric acid.

Wyoming. — Native sulphur has been mined in Wyoming near Cody (12), and near Thermopolis (11), the mode of occurrence at the two localities being almost identical. At the latter locality the deposits are found in the altered Embar (middle Carboniferous) limestone which immediately underlies a travertine deposit (Fig. 102).

The sulphur occurs in small yellow crystals filling veins or cavities in the rocks, and in massive form as a replacement of calcium carbonate by sulphur, the original structure of the limestone being retained.

The distribution of the sulphur appears to be very irregular, and confined to those portions of the limestone surrounding the channels of the hot springs that deposited the travertine. The attempted explanation of the origin of the deposits is that surface waters worked their way downward along the sandstones from the Owl Creek Mountains (Fig. 102), and came into contact with some uncooled body of igneous rock, which not only heated them, but also supplied them with hydrogen sulphide. Following this they passed upward through the much-fractured beds of the anticline with which the deposits are associated. As these waters approached the surface, the sulphur was precipitated by oxydation. Hot springs carrying both H_2S and CO_2 exist there at present.

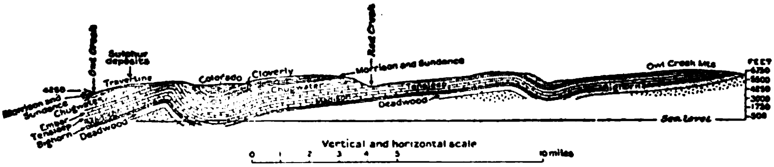

FIG. 102. — Section showing stratigraphy and structure from crest of Owl Creek Mountains to Owl Creek, and relations of sulphur deposits near Thermopolis, Wyo. (*After Woodruff, U. S. Geol. Surv., Bull.* 380.)

The depth of the deposits at these two localities is not believed to be great, but in the rich pockets the sulphur may form 30 to 50 per cent of the rock.

Other States. — Sulphur deposits have been worked in Colorado and Nevada, (1), while occurrences of possible value exist in Texas (7, 9) and California (2).

Sicily is the most important source of supply for the United States. There the sulphur is found in veinlets and cavities in a cellular Miocene limestone, which underlies and overlies gypsum. The sulphur-bearing beds are generally from 3 to 10 feet thick and vary in their thickness as well as dip, the latter being from 25° up to 70°. The percentage of sulphur varies from 8 to 25 per cent, the first figure representing the lowest economic limit. The mines contain more or less petroleum and bitumen, and sometimes even explosive gases, while barite and celestite are associated minerals. Owing to improper methods of mining, there is much waste.

Uses of Sulphur. — The most important use of sulphur is for the manufacture of sulphuric acid and in paper manufacture. Some is also used in making matches, for medicinal purposes, and in making gunpowder, fireworks, insecticides, for vulcanizing india rubber, etc.

In recent years pyrite has largely replaced sulphur for the manufacture of sulphuric acid, and the increase in price of Sicilian sulphur has helped this.

The greater portion of the world's supply of sulphur is obtained from Sicily, the United States consuming the largest amount.

Production of Sulphur. — The sulphur industry of the United States has grown rapidly in the last few years, and in 1907, for the first time in its history, the value of the importations fell below the million dollar mark, due to the great decline in the imports of crude sulphur. Louisiana continues to be a great producer, and the competition of the product from this state with imported Sicilian material has reacted somewhat disastrously on the latter.

The production for 1904 to 1908 is given below.

PRODUCTION OF SULPHUR IN THE UNITED STATES, 1904–1908

YEAR	LONG TONS	VALUE
1904	127,292	$2,663,760
1905	181,677	3,706,560
1906	294,153	5,096,678
1907	293,106	5,142,850
1908	369,444	6,668,215

SULPHUR IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES, 1904–1908, IN LONG TONS

YEAR	CRUDE		FLOWERS OF SULPHUR		REFINED		ALL OTHER[1]		TOTAL VALUE
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	
1904	127,996	$2,462,360	1,332	$39,133	163	$4,373	41	$5,403	$2,511,269
1905	82,961	1,528,136	572	16,037	779	19,960	27	3,352	1,567,485
1906	72,404	1,282,873	1,100	29,565	709	17,918	28	3,224	1,333,580
1907	20,399	355,944	1,458	41,216	606	14,589	60	8,426	420,175
1908	19,620	318,577	793	22,562	693	17,227	30	4,013	362,379

[1] Includes sulphur lac and other grades not otherwise provided for, but not pyrite.

The imports came mainly from Italy and Japan. The exports in 1908 amounted to 27,894 long tons, valued at $561,534, this being nearly 7000 tons in excess of the total importation for consumption.

These figures indicate that the country is producing more than enough sulphur to supply its own needs.

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PYRITE

Properties and Occurrences. — Pyrite, FeS_2, when chemically pure, has 46.6 per cent iron and 53.4 per cent sulphur, and occurs in well-defined cubes or modifications of the same, in irregular grains or as granular masses, of a brassy yellow color.

It is widely distributed in nature, being found in many kinds of rocks and in all formations, and in these may occur as disseminated grains, in contact zones, as concretions in sedimentary rocks, in fissure veins, and as lenticular bodies of variable size usually in metamorphic rocks.

Pyrite as mined is never chemically pure, but contains admixtures of other sulphides, as well as non-metallic minerals.

If chalcopyrite is present in sufficient quantity to bring the copper content of the ore above 3 or 4 per cent, the material may be sold for copper making instead of acid manufacture. Pyrrhotite is abundant in some of the Virginia deposits. In some regions the pyrite carries enough gold to render its extraction profitable, but such deposits are not worked for their sulphur contents.

Pyrite as offered to the trade rarely contains over 43 per cent sulphur, and if the content falls below 38 per cent, the acid makers object. Careful sorting and jigging of the pyrite is usually necessary.

When pyrite is roasted SO_2 is given off, which is changed to SO_3 by mixing with fumes given off from a mixture of $NaNO_3$ and H_2SO_3 in properly constructed lead chambers. In thoroughly roasted pyrite there remains a residue of iron oxide, which is known as "blue billy" or purple ore, and can be used in the blast furnace for iron manufacture. The roasted chalcopyrite is sometimes also used for copper making.

Distribution in the United States. — The most important domestic occurrences are found in a belt of pre-Cambrian metamorphic rocks extending from New Hampshire to Alabama (8), in which the pyrite occurs in lenticular deposits. Virginia and New York are the most important eastern producers. California is the only western state producing appreciable quantities.

Virginia (7, 8). — The counties of Louisa and Prince William contain workable deposits of pyrite, which have been most extensively developed, and yield a little more than half of the total domestic production.

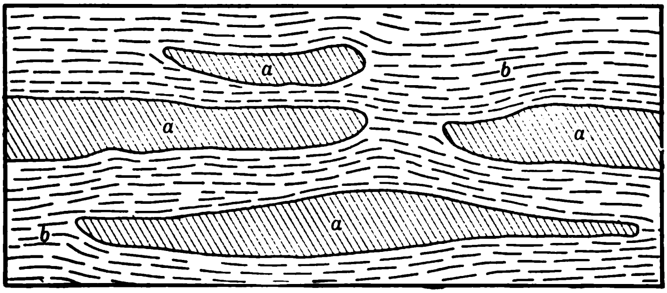

FIG. 103. — Plan of pyrite lenses at Sulphur Mines, Louisa County, Va., showing pyrite (*a*) and crystalline schists (*b*). (*After Watson, Min. Res., Va.,* 1907.)

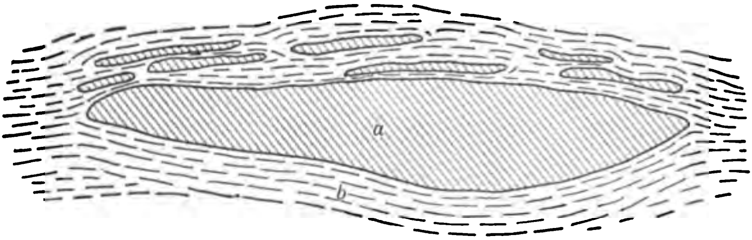

FIG. 104. — Plan of pyrite lens (*a*), showing stringers of pyrite, interleaved with schists (*b*) on hanging wall. Arminius mine, Louisa County, Va. (*After Watson, Min. Res., Va.,* 1907.)

In these counties the pyrite occurs as bodies of lenticular shape (Figs. 103, 104), in quartz-mica schists, which may contain more or less hornblende and garnet locally developed. The schists, which are completely and thickly foliated, have a general strike of N. 10 to 20° E., and a variable dip.

The pyrite is massively granular, and the associated minerals in the order of their importance are sphalerite, chalcopyrite, galena, pyrrhotite, and magnetite. Calcite, quartz, green hornblende, and red garnet are present, but the last two rather favor the margin of the ore besides.

The lenses of pyrite follow each other along the strike, sometimes overlapping, and may also be connected by stringers of ore (Fig. 104). The main bodies may be several hundred feet long, indeed one in Louisa County has a length of 700 feet and a thickness of 60 to 80 feet. Another in Prince William County is 1000 feet long. Pinches and swells are common, and while the pyrite bodies are usually sharply defined, they may at times grade into the country rock.

An analysis of Louisa County pyrite gave: S, 49.27; Fe, 43.62; Cu, 1.50; Zn, .38; insol., 4.23; CaO and MgO, 1.32. Traces of arsenic may be present. The sulphur averages 43 to 45 per cent.

Watson considers that the inclosing schists are undoubtedly metamorphosed sedimentary limestones, as shown by the presence of bands and stringers of impure limestones and the abundant development of lime-bearing silicates. The pyrite is believed to have been formed by replacement.

The ore is worked by underground methods, the schist picked out, and the pyrite crushed and jigged. The entire output is used for acid making. The gossan of the pyrite was originally worked for iron ore.

Sulphuric acid is also obtained from the pyrrhotite-chalcopyrite deposits of Carroll County, etc. These are mentioned under Copper.

New York (2). — Pyrite deposits are worked near Canton and Gouverneur, St. Lawrence County. The pyrite is low grade, carrying 20 to 35 per cent sulphur which can be raised to 45 to 50 per cent by concentration. The ore deposits, which are associated with crystalline limestones and schists of the Grenville series, appear to represent impregnation zones in the schist, which by local enrichment may give lens-like accumulations.

Massachusetts (3, 5). — Pyrite is produced near Davis, Franklin County. The material forms a somewhat tabular deposit of irregular width in steeply dipping, northeasterly striking, crystalline schists. The deposits have been opened up along the strike for about 900 feet, and to a depth of 1400 feet on the dip. Horses of country rock occur in the pyrite. Five feet is regarded as the minimum workable thickness. Garnets and chalcopyrite are present, the latter forming either masses or veins in the pyrite. An analysis of the pyrite concentrates yielded, S, 47 per cent; Fe, 44 per cent; SiO_2, 3 per cent; Cu, 1.5 per cent; Zn, trace; As, none.

Other States. — Some pyrite is produced from deposits in crystalline schist in Clay County, Alabama (8), near Acworth and Villa Rica, Georgia, and in California (1). In Indiana, Illinois, and Ohio some is obtained as a by-product in the mining of coal (6).

Uses of Pyrite. — Pyrite is used chiefly and in increasing quantities for the manufacture of sulphuric acid and sulphate of iron, while small amounts are consumed in the manufacture of mineral paint. It is not used as an ore of iron, except in the form of roasted residues. Recent experiments have demonstrated the possibility of saving the sulphuric acid gas from the roasting of zinc ores, and the utilization of pyrrhotite for making sulphur and sulphuric acid.

Production of Pyrite. —

PRODUCTION OF PYRITE IN THE UNITED STATES, 1904–1908, IN LONG TONS

STATE	1904			1905			1906		
	QUANTITY	VALUE	Average Price per Ton	QUANTITY	VALUE	Average Price per Ton	QUANTITY	VALUE	Average Price per Ton
Alabama and Georgia .	18,369	$76,101	$4.14	19,928	$71,863	$3.61	26,173	$78,817	$3.01
California	26,902	132,905	4.94	61,748	247,712	4.01	52,926	236,867	4.48
Indiana	4,465	16,242	3.64	3,107	11,491	3.70	2,579	7,179	2.78
Massachusetts and New York[2]	31,837	132,889	——	[3]36,090	148,648	——	46,218	162,615	3.52
Ohio	4,837	15,918	3.29	8,944	32,770	3.66	4,732	14,439	3.05
Virginia	120,671	440,753	3.65	123,183	426,008	3.46	128,794	431,388	3.35
Total	207,081	$814,808	$3.93	253,000	$938,492	$3.71	261,422	$931,305	$3.56

STATE	1907			1908		
	QUANTITY	VALUE	Average Price per Ton	QUANTITY	VALUE	Average Price per Ton
Alabama and Georgia .	28,281	$85,307	$3.02	23,915	$69,635	$2.91
California	51,950	174,549	3.36	30,545	131,744	4.31
Indiana	[1]4,929	14,713	2.98	[1]4,905	14,157	2.89
Massachusetts and New York[2]	30,671	126,991	4.14	[4]40,362	186,126	4.61
Ohio	6,816	20,803	3.05	6,531	19,929	3.05
Virginia	124,740	372,586	2.99	116,340	435,522	3.74
Total	247,387	$794,949	$3.21	222,598	$857,113	$3.85

[1] Includes the production of Illinois.

[2] Includes some from New Jersey in 1904 and 1905.

[3] Includes South Dakota.

[4] Includes the production of Wisconsin.

Imports. — The imports of pyrite have increased steadily up to 1908, in which year they amounted to 668,117 long tons, valued at $2,624,339. They came chiefly from Spain, Portugal, Canada, and Newfoundland.

World's Production. — This is given for 1906, that being the latest year for which complete statistics are available.

WORLD'S PRODUCTION OF IRON PYRITE IN 1906

COUNTRY	LONG TONS	COUNTRY	LONG TONS
Portugal	345,222	Newfoundland	28,132
United States	261,422	Sweden	21,483
France and Algeria	261,084	Bosnia and Herzegovina	13,262
Norway	194,770	United Kingdom	11,140
Germany	193,869	Belgium	894
Spain	186,023		
Italy	120,437	Total	1,814,210
Hungary	110,849		
Canada	35,365	Sulphur displaced (based on 45 per cent content)	816,395
Russia	30,019		

CONSUMPTION OF SULPHUR IN THE UNITED STATES, 1906–1908, IN LONG TONS

SOURCE	1906	1907	1908
Domestic sulphur and sulphur content of pyrite	411,793	404,430	469,613
Imported sulphur	74,441	22,523	21,136
Sulphur content of imported pyrite [1]	269,135	282,593	300,653
Total domestic consumption	755,369	709,546	791,402

[1] Based on average sulphur content of 45 per cent.

The following table is of interest as showing the quantity of sulphuric acid used in 1900 in different manufacturing industries.[1]

	SHORT TONS		SHORT TONS
Superphosphate	507,462	Mixed acids	18,981
Petroleum refining	196,141	Blue vitriol	15,644
Pickling iron and steel	70,000	Chrome products	6,859
Ammonium sulphate	47,850	Copperas	5,203
Alum and aluminum sulphate	47,665	Epsom salts	1,843
Nitric acid	36,742	Scattering	50,000
Hydrochloric acid	30,264		1,034,659

REFERENCES ON PYRITE

1. Anon., Cal. State Min. Bur., Bull. 38 : 349, 1906; and Bull. 23 : 144. 2. Newland, N. Y. State Museum, Bull. 93 : 945,1905.; Bull. 102 : 122, 1906; Bull. 132 : 51, 1909. (N. Y.) 3. Phalen, U. S. Geol. Surv., Min. Res., 1908. (Brief description, Mass. and Va.) 4. Phillips, Amer. Fert., XXVI : 10, 1907. 5. Rutledge, Eng. and Min. Jour., LXXXII : 674, 724, and 772, 1906. (Mass.) 6. Struthers, Min. Indus., XI : 577, 1903. (General.) 7. Watson, Min. Res., Va., Lynchburg, 1907 : 190. (Va.) 8. Wendt, Sch. of M. Quart., VII : 218, 1885. (Alleghanies deposits.)

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[1] Min. Indus., XIV : 702.

TALC AND SOAPSTONE

Properties and Occurrence. — Talc, a hydrous magnesium silicate [$H_2Mg_3(SiO_3)_4$], is a widely distributed mineral, but rarely occurs in large quantities.

It is characterized by its extreme softness, soapy feel, and freedom from grit. The color is white, gray, or green; and though generally foliated, it may be fibrous.

Soapstone is a term ordinarily applied to a dark, bluish gray or greenish rock, composed essentially of talc, but containing other minerals as impurities, such as mica, chlorite, amphibole (tremolite), pyroxene (enstatite), and also quartz, magnetite, pyrrhotite, and pyrite. It too is soft enough to be easily cut with a knife, and has a pronounced soapy or greasy feel.

Talc is an alteration product of other magnesia minerals, such as tremolite, actinolite, pyroxene or enstatite, and is often associated with talcose or chlorite schists, serpentine, and such basic igneous rocks as peridotite and pyroxenite. It is also found associated with dolomite.

Soapstone, which often forms large masses, is found chiefly in association with the older crystalline rocks. In some cases, it has no doubt been derived from an altered eruptive rock, but in others probably from magnesian sediments by metamorphism.

Distribution in the United States. — The production of talc and soapstone is limited almost exclusively to the belt of old crystalline rocks forming the axis of the Appalachian Mountain system, and although quarried in eight or ten states, but few are important producers, and these are mentioned below.

Deposits of talc and soapstone are known in some of the western states, but commercial conditions are not at present favorable to their development. Small quantities of talc have been produced in the past in both California and Washington.

Virginia (10). — This state is the most important producer of soapstone, and while the material is found at a number of localities in the state, nearly the entire production comes from a narrow northeast belt at least thirty miles long, extending from Nelson into Albemarle counties.

The soapstone occurs in a number of sheet-like masses called "veins," 30 to 165 feet in thickness, and separated by intervals of 500 to 800 feet.

The deposits dip southeast 60°, conformable with the inclosing crystalline schists, which vary from a mica-quartz schist to a micaceous sandstone. Occasionally the wall rock is a dark graphite schist, or an altered basic eruptive.

The soapstone varies in color from light bluish gray to dark greenish gray, the former or higher grade containing the most talc, and being the easiest and most satisfactory to work.

Under the microscope the better grade is seen to consist mostly of talc, with small quantities of chlorite, magnetite, as well as traces of amphibole and pyroxene. The dark green soapstone owes its color and greater hardness in part to chlorite and other silicates, such as hornblende and pyroxene. The product is used mainly for laundry tubs, while smaller amounts are converted into table tops, sinks, and switch boards. Much of it is shipped to foreign markets.

New York (8). — All of the talc mined in the state is obtained from a small area southeast of Gouverneur. The most abundant country rocks of this area are pre-Cambrian gneisses, in which there occur irregular northeast-southwest belts of crystalline limestone, the greater portion of which is impure. The schistose layers of impurities carry tremolite and enstatite as their chief constituents, and it is the alteration of these that has produced the talc, the change being indicated by the following equations: —

$$\underset{\text{Enstatite}}{4\,MgSiO_3} + H_2O + CO_2 = \underset{\text{Talc}}{H_2Mg_3Si_4O_{12}} + MgCO_3$$

$$\underset{\text{Tremolite}}{CaMg_3Si_4O_{12}} + H_2O + CO_2 = \underset{\text{Talc}}{H_2Mg_3Si_4O_{12}} + CaCO_3$$

This change of the enstatite and tremolite to talc is supposed to have been accomplished by the action of water charged with CO_2, but whether it occurred at shallow or greater depths is uncertain. The talc layer, which varies in thickness from a few feet to over 50 feet, averaging about 20, shows either a fibrous or bladed structure. It is used mainly as a filler for writing papers, being even exported to Europe.

North Carolina (6). — The talc deposits of this state form an interesting contrast with those of Virginia, for here the material occurs as a series of lenticular masses and sheets in blue and white Cambrian marbles, thus indicating its probable derivation from a sedimentary rock. In other deposits the talc is found in a Cambrian conglomerate, in Archæan rocks associated with peridotite, showing an undoubted derivation from igneous rocks.

The first-mentioned group is associated with the Murphy Marble, in

Swain County, and forms lenticular bodies, with a maximum size of 50 feet thickness and 200 feet length. It crumbles down under weathering action, and the deposits are detected by float material. Most of the North Carolina talc is ground to powder, but some is sawed into slabs, or made into pencils, crayons, gas tips, etc.

Vermont (7). — Talc occurs at a number of localities in Vermont, some of which are worked. That worked at East Granville is a talc schist, inclosed between other schists. That at Chester and Athens occurs in gneiss.

New Jersey (4). — Talc has been found at a number of points in the vicinity of Phillipsburg, New Jersey, and also across the river near Easton, Pennsylvania. The talc occurs with serpentine in dolomite and near pegmatite intrusions. The latter by contact metamorphism developed tremolite, white pyroxene, and phlogopite in the limestone. Later, during break-thrust faulting, accompanying minor folding, squeezing, and faulting in this area, the magnesian silicates were altered by water to talc and other products.

The following analyses from several localities show the kind and quantity of impurities which good talc may contain: —

ANALYSES OF COMMERCIAL TALC

LOCALITY	SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	K_2O	H_2O LOSS ON IGNITION
Kinsey Mine, N. C. . .	63.07	1.56	.67	.30	28.76	.78	tr.	4.36
St. Lawrence Co., N. Y.	62.10	—	1.30	—	32.40	—	MnO 2.15	2.05

Uses. — Talc is marketed as rough talc, sawed slabs, or ground talc. Its peculiar physical character, extreme fineness, softness, and freedom from grit adapt it to a number of uses, of which the following are most important: fireproof paints, foundry facings, boiler and steam-pipe coverings, soap adulterants, toilet powders, dynamite, in wall plasters, for dressing skins and leather, as a base for lubricants, as a filling for paper, and for sizing cotton cloth. It has been used to a slight extent for adulterating food. It can, on account of its softness, be easily sawed or carved, and is extensively used for washtubs, sanitary appliances, laboratory tanks and tables, electrical switchboards, hearthstones, mantels, footwarmers, etc. Most of the New York fibrous talc is used as a paper filler, being better suited for it than the North Carolina product. The compact varieties of pure talc are employed for pencils, and for coal- and acetylene-gas tips.

Pyrophyllite differs from talc chemically, being a hydrous aluminum silicate, instead of a magnesium silicate, but when sufficiently free from grit, it is put to the same use as talc. It is sometimes incorrectly called agalmatolite, because of its resemblance to the true mineral of that name. Deposits, more extensive than those of talc, are found near Glendon, North Carolina (6). It varies from green and yellowish white to white, but in all cases becomes nearly white when dried.

Production of Talc and Soapstone. — The production for the last four years has been as follows: —

PRODUCTION OF TALC AND SOAPSTONE, 1905–1908, BY STATES, IN SHORT TONS

STATE	1905		1906		1907		1908	
	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE
Georgia . . .	[1]	[1]	[1]	[1]	739	$11,473	[1]	[1]
Maryland . .	[1]	[1]	2,956	$23,310	5,064	32,250	[1]	[1]
New Jersey and Pennsylvania	5,796	$38,241	13,981	52,961	17,103	46,871	4,648	$29,118
New York . .	56,500	445,000	61,672	557,200	67,800	626,000	70,739	697,390
North Carolina	4,035	74,690	4,009	66,729	4,085	74,347	3,564	51,443
Vermont . .	8,978	65,525	10,413	101,057	16,200	82,500	10,755	99,743
Virginia . . .	17,665	425,090	23,624	590,800	26,278	631,880	19,616	458,252
Other states [2] .	3,660	33,516	3,989	39,499	2,541	25,726	8,032	65,276
Total . . .	96,634	$1,082,062	120,644	$1,431,556	139,810	$1,531,047	117,354	$1,401,222

[1] Included in "Other states."

[2] Georgia, Massachusetts, and Rhode Island, in 1906; California, Massachusetts, and Rhode Island, in 1907; Georgia, Maryland, Massachusetts, and Rhode Island, in 1908; California, Georgia, Maryland, Massachusetts, and Washington in 1905.

The total imports of talc in 1908 amounted to 7429 short tons, valued at $97,096, which was a decrease of over 26 per cent in quantity from 1907, but an increase of 4 per cent in the average price per ton.

REFERENCES ON TALC AND SOAPSTONE

1. Anon., U. S. Geol. Surv., Atlas Folio, 162, 1908. (Pa.) 2. Anon., Maryland Mineral Industries, 1896–1907, Md. Geol. Surv., special publication, VIII, Pt. 2, p. 160. (Md.) 3. Keith, U. S. Geol. Surv., Bull. 213 : 443, 1903. (N. Ca.) 4. Peck, N. J. Geol. Surv., 1904 Rept. : 163, 1905. (N. J. and Pa.) 5. Perkins, Eng. and Min. Jour., LXXXVI : 753, 1908. (Vt.) 6. Pratt, N. Ca. Geol. Surv., Econ. Papers, No. 3 : 99, 1900. (N. Ca.) 7. Pratt, U. S. Geol. Surv., Min. Res., 1905 : 1361, 1906. (Vt.) 8. Smyth, Sch. of M. Quart., XVII : 333, 1896. (N. Y. and bibliography.) 9. Waldo, Min. Indus., II : 603, 1894. 10. Watson, Min. Res., Va., Lynchburg : 293, 1907. (Va.)

TRIPOLI

Properties and Occurrence. — The term *Tripoli* is somewhat loosely used to include many siliceous substances used for abrasive purposes, but in this place it is restricted to certain siliceous rocks found in Missouri (2, 4) and Illinois (1, 3).

The Missouri tripoli is a light, porous, siliceous rock which has been extensively quarried near Seneca, Missouri, but it is known at other localities in the state, and even in Oklahoma.

The deposits occur in the Boone (Lower Carboniferous) formation (4), consisting of alternating limestones and cherts having an average thickness of 350 feet, and with only an oölitic limestone as an easily recognized bed. The tripoli beds, which occur mostly above the last, are 4 to 12 feet thick, and overlain by chert, gravel, and red clay. Chert may also occur in the tripoli itself, and even form a large proportion of it.

The tripoli is an even-textured, finely porous rock, whose grains are mostly under .01 mm. in diameter, and are probably chalcedony. The following analyses represent the composition of the stone from Seneca, Missouri: —

Analyses of Tripoli from Seneca, Mo.

	1	2	3
SiO_2	98.28	98.10	98.10
Al_2O_3	.17	.24	.24
Fe_2O_3	.53	.27	.27
CaO	tr.	.184	.33
K_2O	.17	—	—
Na_2O	.27	.23	.23
Ign.	.50	1.16	1.17
Org.	—	.008	—
	99.92	100.192	100.34

1. R. N. Brackett, Ark. Geol. Surv., V : 267, 1892. 2. W. H. Seaman, Sci. Am. Supp., July 28, 1894 : 15487. 3. Mo. Geol. Surv., VII : 731, 1894.

A commonly accepted theory is that the tripoli results from the decomposition of chert, but while chert is in the tripoli beds, it is not possible to find a transition from tripoli laterally to unaltered rock. It is also difficult to see how the common chert of this region could form the massive, non-fossiliferous tripoli.

Siebenthal (4) believes the tripoli to have been derived by the leaching of lime carbonate from beds like certain gray, dull, massive limestones now found in this region.

Uses. — The rough blocks are sawed up into filter stones, while the spalls and small pieces are ground up for tripoli flour, and there has been a great increase in the production since 1885. The tripoli is worth $6 to $7 per ton f.o.b. Tripoli stone is used to some extent for blotter blocks and scouring bricks. Tripoli flour is used as an abrasive for general polishing, burnishing, and buffing, and also as an ingredient of scouring soaps.

In southern Illinois, in Union and Alexander counties, there are beds of fine-grained silica, which may be similar to the Missouri tripoli. Its origin and extent are, however, imperfectly known. An analysis yielded SiO_2, 98.00; MgO, .20; Al_2O_3, 1.21; Moist., .15; Und., .44. The silica consists of minute particles from .50 to .2 mm. diameter, of crystalline structure, transparent character, and irregular shape, loosely cemented by a small amount of clay. It may be used for wood polishing and other purposes.

REFERENCES ON TRIPOLI

1. Bain, Ill. Geol. Surv., Bull. 4:185, 1907. (Illinois.) 2. Hovey, Sci. Amer. Suppl., July 28, 1894, p. 15487. (Missouri.) 3. Parr, Ernest and Williams, Jour. Indus. and Eng. Chem., I : 692, 1909. (Illinois.) 4. Siebenthal and Mesler, U. S. Geol. Surv., Bull. 340 : 429, 1908. (Missouri.)

WAVELLITE

Wavellite has been used to a small extent in the United States as a substitute for rock phosphate, in making phosphorus.

This mineral does not usually occur in minable quantities, but a somewhat unique deposit has been found on South Mountain, near Mount Holly Springs, Pa. There the wavellite occurs in a white residual clay derived from talcose schists, and associated with manganese and iron ores. The iron and manganese have been concentrated during the weathering of the rocks, and deposited in the residual materials, near the contact of the limestones of the valley and the mountain sandstones. The phosphate occurs as nodules, scattered through a white clay, lying between a manganese-bearing red clay and the mountain. The width of the deposit is 40 to 50 feet. The mining of this material was reported by the United States Geological Survey for 1906, but since then no production has been recorded.

Phosphorus is used mainly for making matches as well as for fuse compositions, rat and insect poison, phosphoric acid, and for other compounds used in medicine and the arts. It is also used in the preparation of precious metals, electrotyping, and in phosphor bronze.

REFERENCES ON WAVELLITE

1. Stose, U. S. Geol. Surv., Bull. 315 : 325, 1907. 2. Hopkins, Ann. Rept. Pa. State College, 1889–1900, appendix III : 13.

Plate XXIX

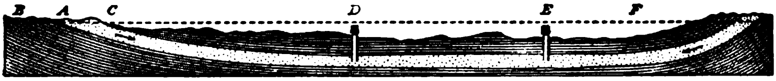

Fig. 1. — Section of an artesian basin. *A*, porous stratum; *B*, *C*, impervious beds below and above *A*, acting as confining strata; *F*, height of water level in porous bed *A*, or, in other words, height in reservoir or fountain head; *D*, *E*, flowing wells springing from the porous water-filled bed *A*.

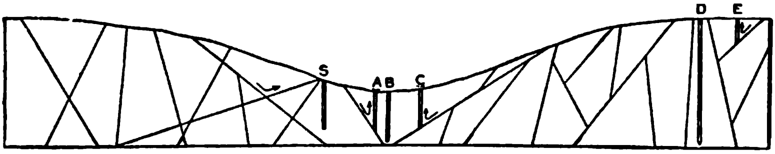

Fig. 2. — Section illustrating artesian conditions in jointed crystalline rocks without surface covering. *A*, *C*, flowing wells fed by joints; *B*, intermediate well between *A* and *C* of greater depth, but with no water; *D*, deep well not encountering joints; *E*, pump well adjacent to *D*, obtaining water at shallow depths; *S*, dry hole adjacent to a spring, showing why wells near springs may fail to obtain water.

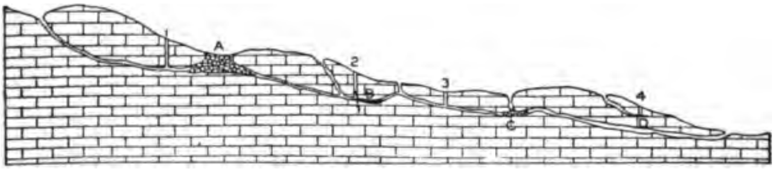

Fig. 3. — Section illustrating conditions of flow from solution passages in limestone. *A*, brecciated zone (due to caving roof) serving as confining agent to waters reached by well 1; *B*, silt deposit filling passage and acting as confining agent to waters reached by well 2; *C*, surface débris clogging channel and confining waters reached by well 3; *D*, pinching out of solution crevice resulting in confinement of waters reached by well 4.

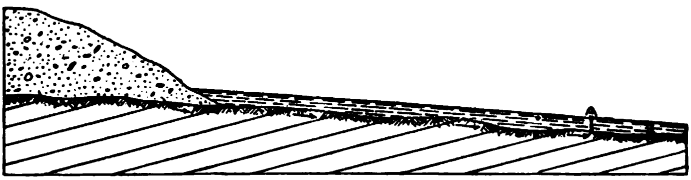

Fig. 4. — Section illustrating conditions of flow from joints, cracks, and solution passages in stratified rocks covered by impervious clays and fed from morainal drift. (*All after Fuller.*)

CHAPTER XIII

UNDERGROUND WATERS

THE investigation of underground waters has assumed such importance in the last few years, that it is hardly possible to do it justice in the limited space which can be devoted to it here. However, some of the more salient points can perhaps be touched upon, and those who desire more detailed information are referred to the selected bibliography at the end of the topic.

While much of the water used for supplying towns and cities, for irrigation purposes, etc., is obtained from below the surface, all of it originates in rainfall. The rain water falling on the surface is disposed of in part by evaporation and surface run-off, but a variable and sometimes large percentage seeps into the ground.

Ground Water (5, 6) — A small part of the water soaking into the ground is retained by capillarity in the surface soil, to be returned again to the atmosphere, either by direct evaporation or through plants; but most of it finds its way into deeper layers of the soil, which it completely saturates.

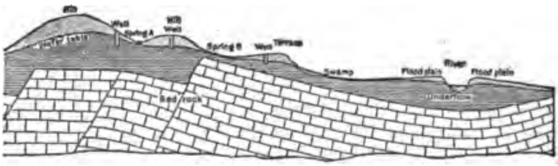

FIG. 105. — Ideal section across a river valley, showing the position of ground water and the undulations of the water table with reference to the surface of the ground and bed rock. (*After Schlichter, U. S. Geol. Surv., Water Supply Bull.* 67.)

The water in this saturated zone, which is termed the *ground water* (Fig. 105), forms a great reservoir of supply for lakes, springs, and wells; and its upper surface, known as the water table, agrees somewhat closely with that of the land surface, but is farther from it under hills (Fig. 105), and nearer to it under the valleys. Under some depressions it may even reach the surface and form springs or swampy conditions (see Fig. 105). The depth of the water table is quite variable, being but a few feet below the surface in moist climates, while in arid regions it may be 100 feet or more.

In any area, however, the water table may show periodical fluctuations, due in part and mainly to variation in the supply. Near the coast line, the rise and fall of the tide may also affect it (Fig. 106). In all ground water there is a slow but constant movement from higher to lower levels, just as in the case of surface waters, so that the ground water flows toward the valleys. There it may discharge into the streams, but in some instances it follows the valley bottom below the river bed, separated from the river water by a more or less impervious layer (6). The composition of the ground water also shows a somewhat close relation to the rocks or soils in which it accumulates.

Artesian Water. — Under this heading are included those waters confined in rocks of consolidated or unconsolidated character, under sufficient pressure to cause the water to rise toward the surface, along an avenue of escape, but not necessarily high enough to produce an outflow.

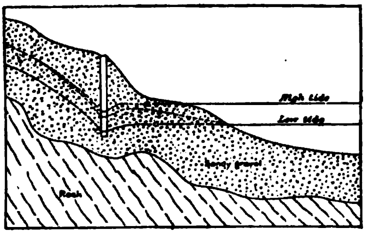

FIG. 106. — Section showing effect of tide on level of water table. (*After Ellis, U. S. Geol. Surv., W. S. Bull.* 232.)

The artesian water found in rocks may collect there in cavities of diverse size, origin, and shape, such as pores between the grains, joint cracks, bedding planes, solution cavities, cavities due to brecciation, gas cavities of lavas, etc. (Pl. XXIX). The surface water finds its way down into these open spaces in the rocks, and if there is some confining agent, such as denser rock, or other more or less impermeable barrier, present, it may be held there. Under these conditions it may be under more or less pressure and if some avenue of escape, such as a drill hole, is opened up, the water rises towards the surface.

The requisite conditions of an artesian flow might therefore be stated as follows (2): (1) adequate source of water supply; (2) a retaining agent offering more resistance to the passage of water than the well or other opening; (3) an adequate source of pressure.

The retaining agent may be a stratum, vein, or dike wall, joint, fault, a water layer, etc., while the pressure is due primarily to variations in level in the different parts of the artesian system, although there may be numerous modifying factors. It will be understood, from what little has been stated above, that a supply of artesian water might be found under a variety of conditions. Only two of these will be considered here, although several others are shown in Pls. XXIX and XXX.

Stratified Beds. — The structure sometimes found in stratified rocks closely approaches the most favorable conditions for an artesian circulation. That is, we have inclined layers of pervious rock, inclosed between beds of impermeable, or but slightly permeable, character. Water flowing down these permeable beds, either through the pores, or in the pores and joints together, may accumulate in sufficient quantity to yield a large and sometimes steady supply. While sandstones usually show the highest porosity of any of the sedimentary rocks, limestones may also yield a good flow, although in these the water must accumulate largely in the joint planes. Such a structural type, composed of water-bearing beds between denser ones, may be termed an artesian slope (Pl. XXIX, Fig. 1), and it is of great importance. The wells tapping such a supply are sometimes many miles from the area of intake, and may be sunk to depths of as much as 2000 feet in order to reach the water-bearing bed. A more or less tight bed over the porous one is essential, but the underlying bed need not be impervious.

A not uncommon type of artesian reservoir is that found in glacial drift where water-bearing lenses of sand or gravel are overlain or more or less surrounded by clay. In this case the water seeping downward from the surface collects in the gravel pocket.

There are many areas in the United States in which the conditions are favorable to an artesian water supply in stratified rocks, as the various state and government reports will show. A few of the more important ones may be briefly referred to.

Along the Atlantic and Gulf coastal plain an abundant supply of artesian water is obtained from the Cretaceous and Tertiary beds at depths varying from 50 feet along the inland border, to 1000 feet and over along the coast (7, 10, 22, 41, 48) (Fig. 107).

A second area is that of the upper Mississippi Valley (50), in which an abundant supply of potable water is obtained from the St. Croix and St. Peters sandstone, whose outcrop in Minnesota and Wisconsin covers some 14,000 square miles.

In the Great Plains (8) region water is obtained from the Dakota sandstone, whose collecting area is around the border of the Black Hills (Fig. 108) and eastern edge of the Rocky Mountains. This source is available in South Dakota and eastern Nebraska and Kansas and Colorado. The chief use of the water in this region is for irrigation.

For the arid regions of the west this source of supply has been of inestimable value, and has been the means of reclaiming many an area of hitherto useless land.

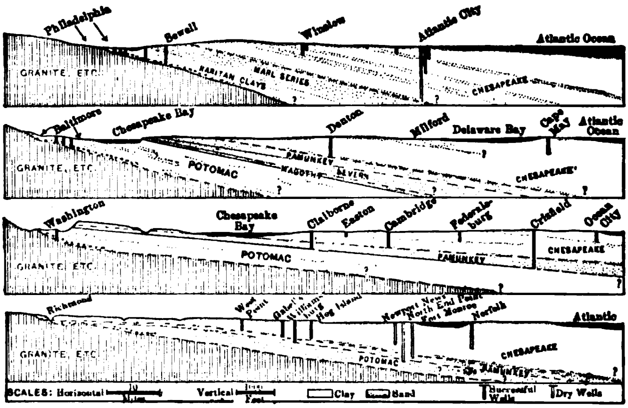

FIG. 107. — Geologic section of Atlantic Coastal Plain, showing water-bearing horizons. (*After Darton, Amer. Inst. Min. Engrs., Trans. XXIV.*)

Crystalline Rocks. — Recent investigations have shown that a considerable amount of water may seep downward along the vertical joint planes of crystalline rocks (Pl. XXIX, Fig. 2), such as granite, crystalline limestone, gneiss, and schist, and become stored in the horizontal joint fissures, but owing to the density of these rocks, very little water can accumulate in the pores. If now a well is drilled so as to strike these water-bearing joints, a more or less steady supply may be obtained. In most cases the volume is not more than 10 gallons per minute, but occasionally as much as 90 gallons has been obtained by pumping.

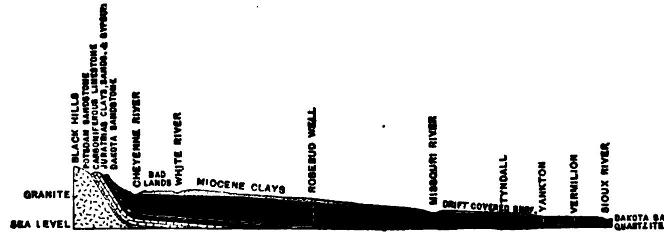

FIG. 108. — Section from Black Hills across South Dakota, showing artesian well conditions. (*After Darton.*)

While the finding of a supply of water in crystalline rocks is more

PLATE XXX

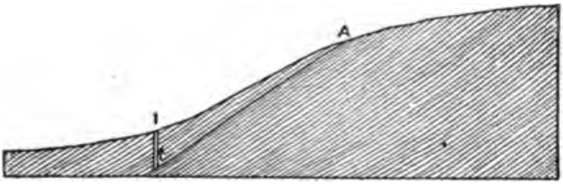

FIG. 1. — Section illustrating conditions of flow from foliation and schistosity planes. *A*, Foliation plane feeding flowing well 1. (*After Fuller.*)

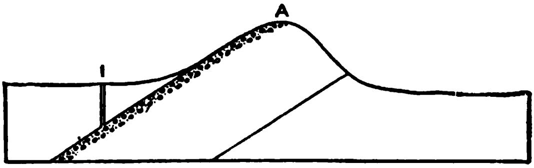

FIG. 2. — Section illustrating conditions of flow from vesicular trap. *A*, Vesicular zone feeding well 1. (*After Fuller.*)

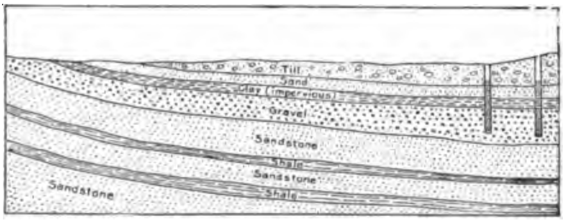

FIG. 3. — Section showing accumulation of water in stratified rocks with low intake. (*After Ellis.*)

or less a matter of chance, still the proportion of successful wells is large, although the possibility of success decreases greatly below 200 feet, and is less even below 50 feet than above it.

A number of wells have been bored in the crystalline rocks of New England and even other eastern states (3, 21, 31).

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MINERAL WATERS

This term is commonly applied to those spring waters containing a variable amount of dissolved solid matter of such character as to make them of medicinal value. Their origin, although often regarded as curious, is simple, the dissolved substances having been derived from the rocks through which the spring waters have circulated. Many mineral waters contain carbonic and even other acids, and alkalies, which further increase their powers of solution. There is apparently some connection between hot mineral springs and geological structure, as they are more abundant in regions of faulting or recent volcanic activity. Waters flowing from shallow sources usually show the lowest mineralization, and those derived from sedimentary rocks often show a greater quantity of dissolved material than those occurring in igneous rocks.

Springs whose temperature is above 70° F. are termed thermal, those between 70° F. and 98° F. being classed as tepid, and those hotter than this as hot springs. The following will serve as examples to show the temperature of different thermal springs: Sweet Springs, West Virginia, 74° F.; Warm Springs, French Broad River, Tennessee, 95°; Washita, Arkansas, 140° to 156°; San Bernardino Hot Springs, California, 108° to 172°; Las Vegas, New Mexico, 110° to 140°.

The volume of discharge shown by mineral springs is quite variable. The famous Orange Spring of Florida discharges 5,055,000 gallons per hour, while others are as follows: Champion Springs, Saratoga, New York, 2500 gallons; Roanoke Red Sulphur Springs, Virginia, 1278 gallons; Warm Sulphur Springs, Bath, Virginia, 360,000 gallons; Glen Springs, Waukesha, Wisconsin, 45,000 gallons.

While a classification of mineral waters may be geographic, geologic, therapeutic, or chemical, that prepared by A. C. Peale is perhaps as satisfactory as any. He subdivides mineral waters into the following classes: —

Alkaline		
Alkaline-saline	Sulphated Muriated	Sodic Lithic Potassic Calcic Magnesic Chalybeate Aluminous
Saline . . .	Sulphated Muriated	
Acid	Sulphated	
	Muriated	
	Siliceous	Sulphated Muriated

The springs falling in the above groups may be either thermal or nonthermal, and may be either free from gas or contain CO_2, H_2S, N, or CH_4.

Other classifications will be found in references.

Most mineral water classifications are unsatisfactory, partly for the reason that, although they give the important salt present in each class, they do not give the amount, a matter of some importance. Thus it has been pointed out for example that two mineral waters might contain, respectively, 250 and 2000 parts per million of mineral matter of the same relative composition, and would therefore fall in the same class. Both might be *carbonated, sodic, calcic, muriated, alkaline-saline.* Now the former would be satisfactory, but the latter would not only be too *hard* for household uses, but would contain so much salt as to give it a decided taste.

Again, it is important in some cases to know the probable combinations present. To a physician it is immaterial to know whether sulphates present are those of sodium or magnesium, since they have similar medicinal effects. The engineer must know which, as the former is harmless, while the latter forms boiler scale.

Distribution of Mineral Waters in the United States. — There are, according to Peale, between eight and ten thousand mineral springs in the United States, and of this number 695 reported production, 1908. The majority of the commercially valuable mineral springs are located in the eastern United States and Mississippi Valley. West of the 101st meridian they are confined chiefly to the Pacific coast. No thermal springs are known in the New England states. Among the American springs, those at Saratoga, New York, have an international reputation, and compare well with many of the foreign ones. Others of importance are the Hot Springs of Virginia and the Hot Springs of Arkansas.

The following table contains the analyses of several types of mineral waters from the United States: —

ANALYSES OF AMERICAN MINERAL WATERS

CHEMICAL CONSTITUENTS	CONGRESS SPRING, SARATOGA, N. Y. SALINE CARBONATED	EXCELSIOR SPRING, SARATOGA, N. Y. SALINE, CARBONATED	WARM SULPHUR SPRINGS, VIRGINIA CALCIC	HOT SPRINGS, ARK. THERMAL, CARBONATED	RED SULPHUR SPRING, SHARON, N. Y. ALKALINE SALINE, SULPHURETED	LAS VEGAS HOT SPRINGS, NEW MEXICO ALKALINE SALINE	BETHESDA SPRING WAUKESHA, WIS. ALKALINE CALCIC
	gr. per gal.	gr. per gal.	gr. per gal.	gr. per gal.	gr. per gal.	gr. per gal.	gr. per gal.
Sodium carbonate	—	—	—	—	—	5.00	—
Sodium bicarbonate	10.77	8.75	—	—	.49	—	1.26
Sodium sulphate	—	—	—	—	—	16.27	.54
Calcium carbonate	—	—	5.22	3.17	—	11.41	—
Magnesium carbonate	—	—	—				
Calcium bicarbonate	143.40	41.32	—	12.66	12.93	—	17.02
Magnesium bicarbonate	121.76	29.34	—	—	.69	—	12.39
Lithium bicarbonate	4.76	—	—	—	—	Trace	—
Iron bicarbonate	.34	3.00	—	2.17	—	—	.04
Magnesium sulphate	—	2.15	—	—	18.96	—	—
Potassium sulphate	.89	—	1.38	—	—	—	—
Sodium chloride	400.44	166.81	—	—	.33	27.34	.46
Potassium chloride	8.05	—	—	—	—	—	1.16
Potassium bromide	—	1.57	—	—	—	—	—
Sodium bromide	8.56	—	—	—	—	—	—
Sodium iodide	.14	4.67	—	—	—	—	—
Silica	.84	.53	1.72	.38	.45	2.51	.74
Calcium sulphate	—	—	14.53	2.54	96.64	—	—

Production of Mineral Waters. — The production of mineral waters in the United States for the last five years was as follows: —

ESTIMATED PRODUCTION OF MINERAL WATERS, 1904 TO 1908

YEAR	NUMBER[1] OF SPRINGS	GALLONS SOLD[2]	VALUE
1904	484	41,969,145	$6,218,873
1905	564	46,544,361	6,491,251
1906	582	48,108,580	8,028,387
1907	584	52,060,520	7,331,503
1908	695	56,108,820	7,287,269

[1] This is the number of springs reporting sales to the United States Geological Survey.
[2] The statistics include all spring or well water sold for medicinal or table purposes.

RANK OF STATES BASED ON SPRINGS REPORTING, ON QUANTITY SOLD, AND ON VALUE OF OUTPUT, 1908

	NUMBER OF SPRINGS REPORTING	QUANTITY SOLD	VALUE OF MEDICINAL WATERS	VALUE OF TABLE WATERS	TOTAL VALUE
1	Massachusetts	Minnesota	Indiana	Wisconsin	Wisconsin
2	New York	New York	Wisconsin	New York	New York
3	Virginia	Wisconsin	Arkansas	Minnesota	Indiana
4	California	Massachusetts	California	Maine	Minnesota
5	Texas	Ohio	Texas	California	California
6	Pennsylvania	Virginia	New York	Massachusetts	Maine
7	Missouri	Michigan	New Hampshire	New Hampshire	New Hampshire
8	Wisconsin	California	Virginia	Pennsylvania	Arkansas
9	Maine Ohio	Texas	Pennsylvania	New Jersey	Massachusetts
10	Michigan	Pennsylvania	Kansas	Virginia	Virginia

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PART II

ORE DEPOSITS

CHAPTER XIV

ORE DEPOSITS

Definition. — The term *ore deposits* is applied to concentrations of economically valuable metalliferous minerals found in the earth's crust, while under the term *ore* are included those portions of the ore deposit of which the metallic minerals form a sufficiently large proportion and are in the proper combination to make their extraction possible and profitable. The term *ore mineral* can be applied to those minerals carrying the desired metallic elements which occur within the deposit. These ore minerals may in some cases make up the entire mass of the ore.

A metalliferous mineral or rock might therefore not be an ore at the present day, but become so at a later date, because improved methods of treatment or other conditions rendered the extraction of its metallic contents profitable.

A few metallic minerals serving as ore minerals, such as gold, copper, platinum, or mercury, sometimes occur in a native condition; but in most cases the metal is combined with other elements, forming sulphides, hydrous oxides, carbonates, sulphates, silicates, chlorides, phosphates, or rarer compounds, the first five of these being the most numerous. A deposit may contain the ore minerals of one or several metals, and there may also be several compounds of the same metal present.

Gangue Minerals. — Associated with the economically valuable metallic minerals there are usually certain common ones, of metallic or non-metallic character, which carry no values worth extracting. These are termed the *gangue minerals.* They often form masses in the ore deposit which can be avoided or thrown out in mining, but at other times they are so intermixed with the valuable metalliferous minerals that the ore is crushed and the two separated by special methods.

Quartz is the most abundant gangue mineral, but calcite, barite, fluorite, and siderite are also common, while dolomite, hornblende, pyroxene, feldspar, rhodochrosite, etc., are found in some ore bodies.

Origin of Ore Bodies. — The fact that ores form masses of greater or less concentration is explainable in two ways: either they have been formed at the same time as the inclosing rock (*contemporaneous* or *syngenetic*); or else they have been formed by a process of concentration at a later date (*subsequent* or *epigenetic*). The first theory is found to be applicable to some ores in igneous rocks, and probably a few in sedimentary ones, while the second applies to most ore deposits, regardless of the character of the inclosing rock.

It must not be inferred from this, however, that the origin of all known ore bodies has been definitely settled, for a strong difference of opinion sometimes exists among geologists regarding the same deposit, and some have been placed first in one class and then in another; but with all this shifting the number of occurrences falling in the syngenetic class has increased considerably and now includes some large and important ore occurrences.

Syngenetic deposits. — These may be divided into two groups, viz. those of magmatic origin, and those of sedimentary origin.

Magmatic segregations (1, 7, 10, 13, 80, 89). — Under this heading are included a small class of deposits, whose intimate association with igneous rocks seems to prove beyond doubt that they have been derived from the igneous magma by a process of segregation during their crystallization from it.

These separations usually take place during the early stages of cooling, and they form the first of a series of minerals, usually crystallizing out in definite order. The first to separate out from the cooling magma are certain oxides such as magnetite, specular hematite, and more rarely chromite and picotite, together with a few silicates such as zircon and titanite.

Following these come some metallic sulphides, as pyrite and pyrrhotite, while after them the ferro-magnesian silicates separate, and lastly other silicates.

A separation of the heavy metals appears to be characteristic of igneous magmas deficient in acid-forming constituents, but this is not surprising, for a consideration of the composition of igneous rocks shows us that since the basicity of an eruptive rock depends partly on the percentage of the oxides of heavy metals, the basic ones are more apt to yield magmatic separations than the acid ones. In some cases, however, metallic concentrations may occur in acid rocks.

In these segregations it is seen that the metallic minerals which have gathered together to form the ore deposits are simply common accessory, and not important, constituents of the igneous rocks. That is, the ore body and the country rock contain the same minerals, but the relative abundance of the silicates and metals are reversed. As an example: the average percentage of chromium in the rocks of the earth's crust is about .01 per cent. In a peridotite magma it forms about .2 per cent, but in segregations within the magma we find 40 to 60 per cent Cr_2O_3.

Form of Magmatic Ore Bodies. — Ore deposits formed by magmatic segregation not only show a varying degree of concentration, but vary greatly in their size and form. Some exhibit vast dimensions, as the Scandinavian iron ore deposits of Kirunavara and Luossavara (Sjögren); indeed, these are much larger than any of this type known in North America, the nearest approach to them being the nickel deposits of Sudbury, Ontario.

Magmatically segregated ore bodies may occur: (1) as irregularly distributed deposits, which show a transition into the surrounding igneous rock; (2) as deposits on the border of the igneous rock, but lying mainly within the former and sending tongues out into either; or (3) as dikes in the igneous rock. In the latter case they might be regarded as very basic segregations, which have been forced up from below, subsequent to the intrusion of the basic rock itself. (See Iron ore, Wyoming.)

As stated above, the number of ore deposits formed by magmatic segregation is small in number, but the following types can probably be referred to this class:

1. Titaniferous iron ores in basic and intermediate eruptives (Adirondacks, New York, Iron Mountain, Wyoming, etc.), and perhaps some iron ores in acid eruptives (Mineville, New York).
2. Chromite in peridotites and the secondary serpentines.
3. Some sulphide ores (Sudbury, Ontario, and Lancaster, Pennsylvania (?).
4. Nickel-iron ores in eruptive rocks (no value).
5. Platinum in basic eruptives (no value).
6. Tin ores in some pegmatites (South Carolina).
7. Some gold ores in quartz veins (Silver Peak, Nevada).

Syngenetic Deposits of Sedimentary Origin. — If ores in sedimentary rocks are of contemporaneous origin they must have been formed at the same time as the rock in which they occur, the process being either a chemical or mechanical one, similar to that by which the different kinds of stratified rocks have been formed. Two classes might be recognized, viz. (1) interstratified deposits, and (2) surficial deposits or placers.

Interstratified sedimentary deposits. — These may have originated by processes analogous to those which have formed the inclosing rocks. Some may have accumulated by precipitation from sea water or fresh water, a process which is going on even at the present day, as shown by the deposition of limonite in ponds, or the formation of nodules of limonite, pyrite, or manganese on the ocean bottom.

Others may be of mechanical origin, the grains of metallic minerals having been set free by disintegration of rocks on the land, and the particles later becoming segregated, as in the case of magnetite sands, formed along the beaches by wave action. Both types may be subsequently covered up by other sediments, or in rarer cases by igneous flows.

Sedimentary deposits of the two types just mentioned are of tabular form, and thin out horizontally in all directions, but many of them are of great extent (Clinton ores) and even of curiously uniform character. They are sometimes sharply separated from the inclosing rocks, or at others grade into them. Further characteristics to be noted are the absence of fragments of the overlying country rock in the ore, and of veinlets branching off from the bed. If folding of the rocks has occurred, the beds follow the folds. Sedimentary deposits are occasionally enriched by water circulating through the beds and causing a concentration of the contents.

Placer deposits. — Placer deposits now found on the surface are of recent geologic age, thus differing from mechanically formed interbedded ores, and have usually originated by stream action.

When the products of rock decay are washed down the slopes and into the streams, the lighter material is carried off to sea, while the heavier particles such as pebbles and metallic mineral grains remain behind in the stream channels. The metallic fragments by reason of their higher specific gravity settle to the bottom of the channel, and all become more or less rounded by the rubbing action they are subjected to while being moved along by the stream current.

Placer deposits may also be formed along beaches by wave action, while a rare type are those which originate in dry climates by the disintegration of rock, little of the material being removed, except sandy particles which are blown away by the wind.

From what has been said above, one must not get the idea that placer deposits did not form in the past, for they did, and are known to exist in sedimentary formations as far back as the Cambrian. (See Gold, South Dakota.)

Epigenetic Ore Deposits. — These, as previously stated, are of later age than the inclosing rock. In other words, they have been concentrated in the rocks by natural processes.

In order to demonstrate this it is necessary to show: (1) the source of the metals found in the rocks; (2) the existence of a carrier which could transport the metals, in solution probably; and (3) the existence of conditions favorable to the precipitation of the ore.[1]

Occurrence of Metals in the Rocks. — It is well known that metallic minerals in small quantities are widely distributed, in both igneous and sedimentary rocks. Sandberger (76), for example, has shown by analyses the presence of nickel, copper, lead, tin, and cobalt in such minerals as hornblende, olivine, and mica; and Curtis has found traces of silver, gold, and lead in the quartz-porphyries at Eureka, Nevada,[2] and silver, arsenic, lead, copper, and gold in the granite at Steamboat Springs, Nevada.[3] Winslow has pointed out the presence of small quantities of lead and zinc in the limestones of Missouri and Wisconsin (see lead and zinc references), and Wagoner has made similar tests on California sediments (92 *a*). Since, however, the sediments were originally derived from the igneous rocks, it follows that the latter must be the original source of the minerals. It is interesting to note that even in the igneous rocks the metals are not impartially distributed, but that certain metals seem to favor certain rocks.[4] Thus iron, manganese, nickel, cobalt, chromium, platinum, and titanium seem to favor basic rocks; while tin, tungsten, and some rarer metals favor the acid ones.

While the occurrence of metallic minerals in the rocks of the earth's crust is widely recognized, few, perhaps, realize the small percentage existing outside of those concentrated portions, the ore deposits; and the following table, showing the average composition of rocks of the earth's crust,[1] will serve to emphasize this point:—

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[1] In many cases cavities in the rocks offer a favorable point of precipitation, but it is now recognized that open spaces are not necessary for ore deposition.

[2] U. S. Geol. Surv., Mon. VII: 80. [3] *Ibid.* Mon. XIII: 350.

[4] De Launay, Ann. d. Min., Aug., 1897.

Oxygen	47.08	Manganese	.089
Silicon	28.30	Sulphur	.11
Aluminum	7.99	Barium	.09
Iron	4.47	Chromium	.034 –
Calcium	3.45	Nickel	.023 –
Magnesium	2.36	Lithium	.01
Potassium	2.46	Chlorine	.06
Sodium	2.54	Fluorine	.02 +
Titanium	.44	Zirconium	.026 –
Hydrogen	.16	Vanadium	.014 –
Carbon	.13	Strontium	.034
Phosphorus	.11		

An examination of the above figures shows that, of some twenty metals that are of importance to us for daily use, only five, viz. aluminum, iron, manganese, chromium, and nickel, are included in the above list, and that the others must be present in amounts of less than .01 per cent.

Professor Vogt[2] has endeavored to estimate the approximate average amount present of other important (economically) metals, not included in the above table. According to him, the percentage amount of tin, zinc, and lead is expressed by a digit in the third or fourth decimal place, copper in fourth or fifth, silver in sixth or seventh, gold and platinum in seventh or eighth. Mercury would show a slightly larger percentage than silver, and arsenic, antimony, molybdenum, and tungsten, between copper and silver. Bismuth, selenium, and tellurium would be placed between silver and gold in the list.

As actual examples of the amounts present, we may quote the following determinations made on eruptive rocks from several localities.

METAL	PER CENT	LOCALITY
Copper	.009	Missouri
Lead	.0011	Colorado
Lead	.004	Missouri
Zinc	.009	Missouri
Silver	.00007	Leadville, Colo.
Silver	.00016	Eureka, Nev.
Gold	.00002	Eureka, Nev.
Gold	.00004	Owyhee Co., Ido.

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[1] Clarke, U. S. Geol. Surv., Bull. 419: 9, 1910.

[2] Zeitschr. prak. Geol., July and Sept., 1898.

It is quite evident that the percentage of metal normally distributed in the rocks of the earth's crust, as indicated above, is far too low to be regarded as workable ore, for, in order to be classed as such, the rock must contain at least a certain percentage of the metal, which varies not only with the metal, but even with the same metal under different conditions, such as location and nature of ore.

Iron ores, for example, especially low-grade ones, cannot be successfully worked, unless favorably located; whereas gold ores, being of higher unit value, are much less affected by this factor. Again, the nature of the ore has to be considered, some being quite easily treated, but others less so, and here the manner of association comes into consideration. Thus the presence of copper or lead may facilitate the extraction of gold and silver, while zinc hinders it. Lastly, with changed conditions, a rock which was formerly of no economic value may become a profitable ore to work, partly because improved methods of treatment have lowered the cost of production. The quantity of metal necessary in an ore for profitable working is referred to under " Value of Ores " in this chapter.

Mode of Concentration. — It is now generally admitted that water, whatever its source, is an important agent in the concentration of many ores. While cold water, free from impurities, has comparatively little solvent power, the presence of acids or alkalies materially increases its solvent capacity, while heat and pressure have also a great influence. Analyses of mine, spring, and surface waters have shown the presence of many dissolved alkalies and other salts (24), and occasionally small quantities of metals.

The following two analyses, which will serve as examples, give the calculated composition of (1) *vadose*, or shallow water, from the 500-foot level of the Geyser silver mine, Silver Cliff, Colorado, and (2) deep water from the 2000-foot level of the same mine. The ore occurs in rhyolite. The figures are grams per 1000 liters.

	1	2
SiO_2	25.90	24.42
Al_2O_3	—	1.06
Al_2O_3, P_2O_5	.80	—
$FeCO_3$	1.50	7.25
$MnCO_3$	1.70	1.19
$CaCO_3$	93.50	366.03
$Ca_3P_2O_8$	—	tr.
CaF_2	—	tr.

	1	2
$SrCO_3$	—	3.29
$MgCO_3$	42.85	621.84
K_2SO_4	4.20	19.18
KCL	16.60	361.34
KBr, KI	—	tr.
Na_2CO_3	38.70	1489.67
Na_2SO_4	60.50	223.53
$NaNO_3$	—	2.19
$Na_2B_4O_7$	—	tr.
LiCl	—	17.30
CO_2	37.20	1418.61
$PbCO_3$	tr.	1.74
$CuCO_3$	tr.	.04
$ZnCO_3$	.40	.66

The higher percentage of dissolved substances in the deep water is quite marked.

While the importance of hot water as an agent in the formation of ore deposits is clearly recognized by many, and traces of metals in solution are sometimes found, still examples of such deposits now forming are rare.

Weed has described a hot spring near Boulder, Montana (100), which is depositing auriferous quartz, and the deposit is pointed out by him to be identical with silver- and gold-bearing quartz veins of the region between Butte and Helena, Montana. At Steamboat Springs, Nevada, it has been found that the alluvial gravels underlying the hot-spring sinters are cemented by stibnite and pyrite.[1] Of still more interest is the collection, by evaporation, of copper from certain Javan hot springs, in which the metal occurs as iodide of copper.[2]

Lindgren has also recently called attention to the occurrence of certain mineral springs near Ojo Caliente, New Mexico (64), whose strongly alkaline water contains much sodium carbonate as well as fluorine, boron, and barium, the last being present in considerable amount.

The pre-Cambrian gneiss near by contains veinlets of colorless fluorite, probably deposited when the spring waters issued at a higher level. Higher up the slope is a narrow vein, carrying small amounts of gold and silver in a gangue of colorless fluorite and some barite, and capped by a calcareous tufa. The latter is supposed to have been deposited at the surface while the fluorite was precipitated farther down in the vein fissure.

Water is known to be widely (11, 39), but not uniformly, distributed in the rocks of the earth's crust, and much of it is in slow but constant circulation. While it is admitted by most geologists that this water has been an important ore carrier, there exists a difference of opinion regarding its source, one class maintaining that it is largely of meteoric origin, the other that it is derived chiefly from igneous intrusions.

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[1] Lindgren, Amer. Inst. Min. Engrs., Trans. 1905: 275.

[2] Stevens, Copper Handbook, IV: 156, 1904.

Meteoric Waters as Collecting Agents. — That meteoric waters were the most important, if not the only, collecting agents of ores was advocated by many of the earlier geologists, including J. Le Conte,[1] F. Posepny,[2] and L. De Launay,[3] while in recent years the theory of ore formation by meteoric waters has been strongly urged by C. R. Van Hise (12). He points out that the earth's crust may be divided into three zones: (1) an upper zone of fracture, beginning at the surface; (2) a zone of combined fracture and flowage; and (3) a zone of rock flowage, or of no fracture.

In zone 1, or that of rock fracture, the rocks, if rapidly deformed, respond by fracturing. If, however, the deformation is exceedingly slow, folding may result, but it is due to the rock slipping along numerous, small, parallel fractures. The conditions in this zone, then, are favorable for the development of numerous fissures or cavities in the rocks.

Most ore deposits occur within this zone, owing to the existence of favorable conditions for the free circulation of water.

In zone 2, that of combined fracture and flowage, the pressure is sufficient to cause some rocks to flow, while others of greater strength will only be fractured. Other factors, such as rapidity of deformation, temperature at which deformation occurs, and amount of moisture present may affect the result. In this zone, then, fractures may exist in certain rocks but not in others.

In zone 3, that of rock flowage, the pressure is so great that deformation of the rocks is accomplished by flowing rather than breaking, and practically no cavities can exist, as they will be closed up as soon as formed.

Van Hise estimates that at a depth of about ten thousand meters the strongest rocks will be deformed by flowing.

Into this zone of no fracture water from the surface cannot penetrate, but above it there may be active percolation by water. It is well known that rain water, falling on the earth's surface, seeps through the soil into the underlying rocks, permeating them to a variable depth, and forming a more or less saturated zone, whose upper limit, lying at a variable depth, is known as the ground-water level. A second belt of underground-water circulation lies above this, and extends to the surface. The ground-water level is found at a variable depth below the surface. (See Chapter XIII, Underground Waters.)

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[1] Amer. Jour. Sci., July, 1883, p. 1.

[2] Trans. Amer. Inst. Min. Engrs., XXIII, p. 213.

[3] La Recherche Captage, et Amenagement des Sources Thermo-minerales.

The water, filtering down from the surface into the rocks, flows through various openings, such as fissures due to jointing, faulting, stratification, or cleavage, through the pores between the grains, or through irregular openings.

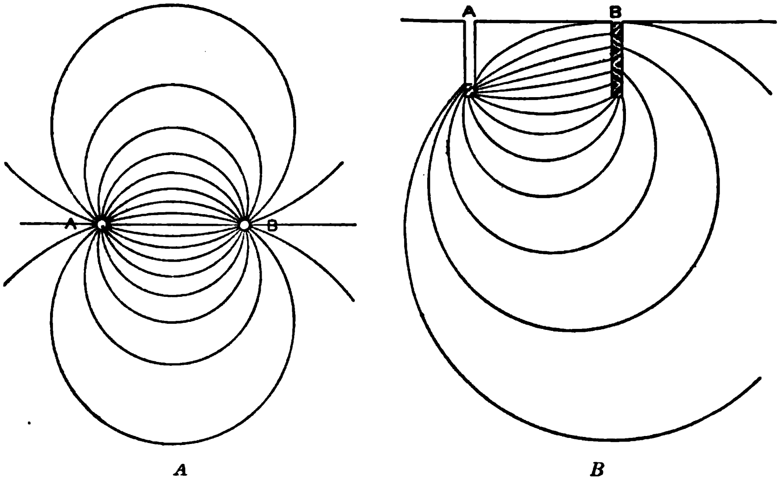

FIG. 109. — *A*, ideal horizontal section, and *B*, ideal vertical section, of the flow of underground water through a homogeneous medium from one well to another. (*After Van Hise.*)

It should be noted, in this connection, that the permeability does not necessarily increase with the porosity, because a highly porous rock might have such small pores as to be but slightly permeable.

While the movements of underground waters are complex, Van Hise points out that they resolve themselves into two components, viz. horizontal and vertical ones, with the horizontal movement being probably the more important. The entering waters then flow downward first by gravity, and then in general laterally, finally emerging again at the surface. The motion is in general from areas of high to low pressure, and the path traversed may be very irregular and circuitous.

Van Hise has indicated graphically the vertical and horizontal paths by which waters might pass from one opening to another (Fig. 109). This shows two wells, separated by a homogeneous porous medium. The well *A* is assumed to be empty, and the well *B* is filled. It will be seen that some of the water takes a very direct course, while other portions follow a very curved path.

Figure 110 shows the circulation of underground waters from higher to lower levels. Of course to produce such uniform percolation must require the presence of homogeneous rocks. There will be a strong tendency for the circulating waters flowing through the pores of the rocks to flow towards, and concentrate in, the larger openings, such as fault planes, joint planes, etc., where several different waters may mingle, and the principal deposition of metals occur (Fig. 110). While gravity is the chief cause of the circulation of the ground waters, other factors are not without influence. Thus, as the waters reach increasing depths, their temperature rises, and this is accompanied by a decrease in the viscosity of the water, accelerating its circulation at those depths.

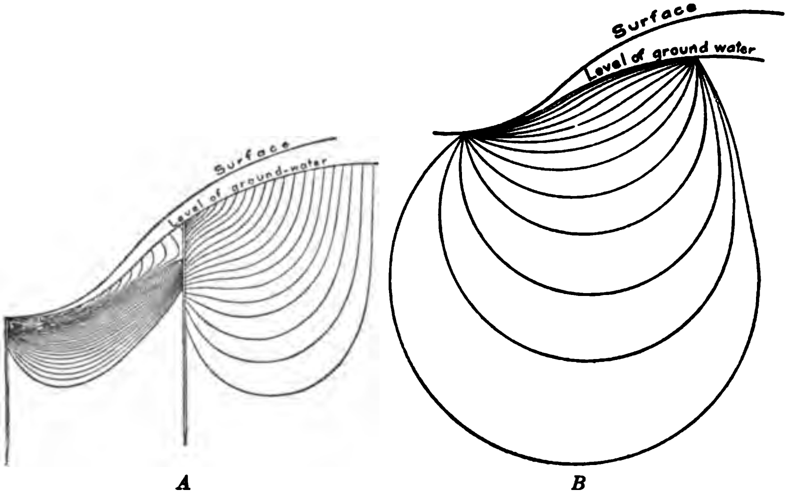

Fig. 110. — Ideal vertical section of flow through a homogeneous medium. *A*, water entering at a number of points on a slope and passing to a valley below, interrupted by two vertical open channels, through which they may ascend. *B*, water entering the ground at one point on a slope and emerging at a lower point. (*After Van Hise.*)

In considering the work performed by ground waters, it is necessary to regard the zone of fracture as divided into two belts, viz. an upper belt of weathering, and a lower belt of cementation. The first, in which the ordinary weathering processes go on, extends to ground-water level. The second lies below this, and is characterized by such changes as cementation, induration, hydration, deposition, and increasing volume of the rocks. They are changes involved in the transfer of mineral matter from one point to another. Now, according to Van Hise's theory the descending waters are dissolving more or less mineral matter from the rocks through which they are percolating, this solution going on mainly in the belt of weathering; but in the belt of cementation deposition is the dominant process. Moreover, since there is a concentration of currents toward cavities or fissures, most of the precipitation will go on there. Furthermore, it is the ascending currents in the larger cavities which are likely to be depositing ones, because in them the temperature and pressure are decreasing, conditions tending to reduce the solvent power and saturation point of the solution.

Solutions of different kinds meeting at the intersection of two fissures might deposit some of their dissolved mineral matter, because of reactions. While the main deposition is performed by ascending solutions, descending waters may become at times depositing ones.

Magmatic Waters as Concentrating Agents (28, 47, 48, 49, 59, 61). — While some ores undoubtedly owe their primary concentration to meteoric waters, still the majority of geologists probably believe that in most cases the work has been performed by magmatic waters.

According to this theory the waters issuing from cooling magmas carry metals with them, which they deposit at varying distances from the intrusive as they rise towards the surface. (See further under Magmatic Emanations.) In addition, these magmatic solutions may also gather some additional metalliferous minerals from the rocks through which they pass. This theory, although it has grown greatly in recent years, is not a new one, for it was suggested by Elie de Beaumont as early as 1850,[1] but its full significance was not grasped until some years later, when the writings of Vogt[2] (in 1894), Spurr,[3] Lindgren (59*a*), and especially Kemp (48) did much to emphasize its importance.

Many of the points brought out have been used as arguments against Van Hise's theory of meteoric circulations, and include the following: Meteoric waters do not reach great depths, in fact probably not more than 2000 feet or sometimes less from the surface, and when they do penetrate to a greater distance, it is because they have followed some fissure. The lower levels of many deep mines are so dry as to be dusty. Ores have been concentrated at a much greater depth than that reached by surface waters. It is perfectly reasonable to regard igneous rocks as an important source of water, and the experiments of Daubree have shown that a molten granite contains a large amount of vapor which it retains while at great depths, but gives off on approaching the surface and cooling. Moreover, vast quantities of steam are emitted by volcanoes during periods of eruption, and certain quickly cooled rocks, such as pitchstones, contain several per cent of water. The suggestion that this water has filtered in from the surface is scarcely conceivable, as the heat of the molten rock would tend to drive it away.

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[1] Geol. Soc. France, Bull. IV : 1249.

[2] Zeitsch. für prak. Geol., II.

[3] U. S. Geol. Surv., 16th Ann. Rept., II.

It is an undeniable fact that most metalliferous veins are found in areas of igneous rocks, and Lindgren (see Metallogenetic Epochs on a later page) has shown that in the case of the gold deposits of North America the periods of vein formation agreed closely with those of igneous activity. It is also a noteworthy fact that, with the exception of some deposits of commoner metals, such as iron, and some copper, lead, and zinc, ores are found in close association with igneous intrusions, which seems to postulate a close connection between igneous rocks and ore deposits, as advocated by such authorities as Weed, Kemp, Lindgren, and Emmons. While the importance of magmatic waters as agents of primary deposition is quite generally admitted, it is true that the metalliferous minerals as originally deposited have not always been sufficiently concentrated to serve as ores, but they have become concentrated at a later date by meteoric waters, as at Bisbee, Arizona. (See Ransome, under copper references.) Posepny (68), in his work on the Genesis of Ore Deposits, distinguishes between descending surface waters, or *vadose* circulations, and ascending waters from great depths. It is the former that have been active in the secondary concentration of ores.

Deposits from Magmatic Emanations. — Under magmatic emanations are included gases, vapors, or liquids, given off by molten magmas during cooling.

In order to point out more clearly the several processes by which ores may be deposited from magmatic emanations it may be well to turn for a moment to the molten magma and consider certain changes which take place during the period referred to.

A study of large intrusive masses has shown us that the molten mass after coming to rest sometimes tends to separate into two parts, the one basic, the other acid, with a gradational zone between. The acid portion may be either the outer or central part of the mass.

A segregation of metallic minerals may occur, though, even if the magma as a whole does not split up. But whether or not such a differentiation occurs, the molten magma, after coming to rest, will cool first in its outer and upper portion, the contraction incident to solidification causing numerous fractures. Into these there may be forced molten rock from the still uncooled lower portions of the mass, or water and gases forced out of the solidifying parts of the magma. This water, however, must be in a vaporous form, because the heat is undoubtedly sufficiently great to raise its temperature above the critical point, and the pressure is likewise heavy. In many cases no doubt the fissure may become filled by a mixture of water and magma, the former in such excess that it may be difficult to say whether this should be called an igneous fusion, or a watery solution, for under pressure water can mix with a magma in all proportions, giving us a series of mixtures, with a fused mass at one end and a hot solution at the other.

Many magmas in cooling give off mixtures of watery vapors and gases (such as fluorine, boron, etc.); and these before leaving the igneous mass no doubt extract metallic or other elements and carry them along, only to deposit them later, either in the outer parts of the cracks in the border of the intrusion or in the surrounding rocks.

As these emanations from the magma get farther away from it, where temperature and pressure are less, the watery vapors condense, and these hot solutions (magmatic or juvenile waters) gradually work their way towards the surface, sometimes reaching it, and flowing out as hot springs.

It is possible and indeed probable that as they reach shallower depths they may become more or less mixed with meteoric waters.

These magmatic emanations with their burden of mineral matter may not only deposit this at a varying distance from the intrusive, but they in many cases often attack the rocks through which they pass, altering them to a marked degree, and in addition dissolve materials from the rocks they permeate.

The kind of materials deposited and the character of the alteration depend to a large degree upon physical conditions, primarily temperature and pressure.

If the deposition and alteration occur while the magmatic emanations are still in a vaporous form (due to high temperature and pressure), the process is termed *pneumatolysis* (gaseous). If it occurs when the water is in liquid form, it is termed *hydatogenesis* (aqueous). In some instances both gases and liquids may be present, the work then being *gas-aqueous* or *pneumato-hydato-genetic.*

It is naturally difficult to prove in many cases whether the phenomena observed were produced by pneumatolytic or hydatogenetic processes.

Certain important types of deposits, formed under these varying physical conditions, may now be referred to.

Tin and Apatite Veins (7, 10, 61, 92). — Around the borders of certain granitic masses there are found pegmatite veins carrying cassiterite, wolframite, etc., as well as fluorspar, topaz, and tourmaline.

The wall rocks of such veins have been strongly attacked, the feldspar and mica especially being replaced by quartz, tourmaline, topaz, lepidolite, etc., giving a rock type known as *greisen.*

It is pretty generally conceded that these veins, which are closely associated with the magma, have been deposited from a mixture of magma, watery vapor, and gases, given off during the cooling. If the first was in excess, the intergrowth of the quartz and feldspar has the appearance of crystallization from fusion, although the coarse texture of these minerals points to the presence of a marked amount of watery vapor. In other cases, however, where it is quite clear that the minerals have grown from the walls toward the center, sometimes incompletely filling the cavity, we are forced to the conclusion that watery vapor was greatly in excess, and that the process is largely if not wholly a pneumatolytic, or at most a gas-aqueous one; moreover, the peculiar kind of alteration of the wall rock indicates the presence of water and gases.

The apatite veins form an analogous group, which are related to basic rocks such as gabbro and contain chlorine as the prominent mineralizing agent in the place of fluorine. They may carry specularite and pyrrhotite as ore minerals, and scapolite, diopside, hornblende, and biotite as silicates.

Contact-metamorphic deposits (53, 54, 60, 97). — These include masses of metallic minerals and silicates which are found in some sedimentary rocks, chiefly calcareous ones, near their contact with igneous intrusions, specially those of a more or less acidic character.

It has long been known that an igneous mass may often exert considerable effect on the rocks which it has penetrated, sandstone, for example, being altered to quartzite, clay or shale to hornstone, and limestone to marble. Moreover, the contact-metamorphism is accompanied by the development of new minerals in the wall rock.

Thus in limestone there may be formed garnet, wollastonite, epidote, diopside, amphibole, wernerite, vesuvianite, etc.; while in aluminous rock such as shale and slate we find andalusite, sillimanite, biotite, etc.

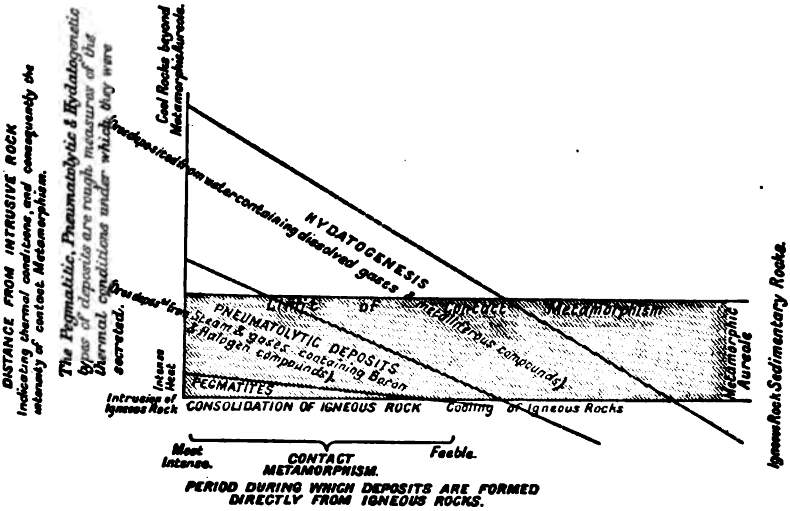
DISTANCE FROM INTRUSIVE ROCK
Indicating thermal conditions, and consequently the intensity of contact Metamorphism.
The Pegmatitic, Pneumatolytic & Hydatogenetic types of deposits are rough measures of the thermal conditions under which they were secreted.
Cool Rocks beyond Metamorphic Aureole.
Ores deposited from water containing dissolved gases & metalliferous compounds
HYDATOGENESIS
Limit of Contact Metamorphism
Ores deposited from Steam & gases containing Boron & Halogen compounds
PNEUMATOLYTIC DEPOSITS
PEGMATITES
Intense Heat
Intrusion of Igneous Rock
CONSOLIDATION OF IGNEOUS ROCK
Cooling of Igneous Rocks
Metamorphic Aureole
Igneous Rock Sedimentary Rocks.
Most Intense.
CONTACT METAMORPHISM.
Feeble.
PERIOD DURING WHICH DEPOSITS ARE FORMED DIRECTLY FROM IGNEOUS ROCKS.

FIG. 111. — Diagram illustrating the relations of the various types of ore deposits directly derived from igneous rocks. (*After Thomas and MacAlister.*)
This figure shows diagramatically the relative width of the zones characterized by different processes (pneumatolytic, etc.), and their contraction as the eruptive cools.

Even until recently it was thought by many that these silicates, as in the limestones, must be segregated and recrystallized impurities, and hence could form only in impure rocks, the pure limestones yielding simply a marble.

Investigation of these contact zones has shown us, however, that they contained many elements which were not found in the limestone outside of this belt of metamorphism, and we are therefore driven to the conclusion that they represent substances which have been given off by the magma and lodged in the lime rock.

The theory usually advanced to explain the origin of these contact-metamorphic deposits is that, during cooling, the magma gave off watery vapor, heated above its critical temperature (365° C.) and under high pressure. With this there were also mineralizing vapors, such as fluorine and boron, and metals as well as silica. The metals are believed by some to have combined with the fluorine or boron to form volatile compounds.[1] These were forced out into the fissures and pores of the limestone, and replaced the latter wholly or in part. The silica, alumina, and iron combined with the lime to form garnets and other silicates, and after these came the metals, which were also deposited by replacement.

In no case did the substances entering the limestone to form the silicates wander very far from the eruptive, because they became locked up in the limestone, where we find the metallic minerals intergrown with the contact silicates.

Contact-metamorphic deposits were probably formed at a considerable distance below the surface, from a depth of not less than one thousand feet to unlimitable ones, provided the heat was not high enough to fuse the sedimentaries. That this has not occurred is shown by the sharp line of contact between the eruptive and the limestone, which is believed by some to warrant the assumption that no melting of the country rock has occurred.

Contact-metamorphic deposits are usually of irregular shape and somewhat bunchy in character, but very little can be said regarding the depth to which they may extend.

The common ore minerals found are magnetite and specularite, mixed with sulphides such as bornite, chalcopyrite, pyrite, pyrrhotite, and more rarely galena and zinc blende. Some gold and silver may also be present, but tellurides are probably very rare. A characteristic feature is the occurrence of both sulphides and oxides, thus differentiating them from fissure veins.

The gangue minerals are in general lime-alumina silicates, and include garnet,[2] wollastonite, epidote, amphibole, pyroxene, zoisite, vesuvianite, quartz, and calcite, but rarely barite, fluorite, apatite, and tourmaline. The first of these is especially abundant and may form nearly the entire mass of the rock.

Contact-metamorphic deposits, though sometimes rich enough to mine where not secondarily enriched, need this process in many cases to make the ore workable. This is well illustrated in the case of the Morenci, Arizona, copper ores.

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[1] The rarity of fluorine and boron minerals in most contact-metamorphic deposits may reasonably cause some to doubt this.

[2] Mainly andradite, the iron-lime garnet, and less often grossularite, the lime-alumina garnet.

Although this class of deposits was recognized by Van Groddeck, as early as 1879, he failed to appreciate the true importance of the associated intrusive. In more recent years the writings of Vogt, Kemp, Weed, Lindgren, and Barrell have greatly increased our knowledge of the true nature of these interesting deposits, and we now know, moreover, that they form a very important and somewhat common type, which in the United States is restricted mainly, however, to the Pacific Cordilleras.

Gold- and Silver-bearing Veins (61, 13). — These as described by Lindgren form a most important class which carry gold and silver, as well as varying amounts of other metals, and have probably been formed at considerable depths, where temperature and pressure were relatively high. They are usually associated with granite intrusions in schists, and show a strong replacement of the country rock.

Ore Deposits formed at Shallow Depths (61, 13). — These include a number of fissure-vein deposits, found in the Cordilleran region, and carrying gold with much silver, as well as subordinate amounts of lead, zinc, and copper. The fact that they are found in flows of volcanic origin indicates their formation at comparatively shallow depths, that is, from a few hundred to four or five thousand feet. They include most of the veins of western Nevada, the San Juan region of Colorado, Cripple Creek, Colorado, district, etc.

Gold and silver are prominent, although the former is more abundant and the native gold usually more finely divided.

Like the deeper veins they may carry pyrite, galena, and sphalerite, but in addition chalcopyrite, arsenopyrite, argentite, and stibnite are characteristic ore minerals. Quartz is a common gangue mineral, and calcite, dolomite, siderite, barite, and fluorite are also found.

Metasomatism varies somewhat with the different rocks. In moderately acid rocks sericitization and even pyritization seem to be common near the vein, and propylitization[1] farther away. In basic igneous rocks, propylitization may extend close to the vein, but sericitization occasionally takes its place. Silicification of the wall rock is common even in calcareous rocks.

This class would also include cinnabar deposits.

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[1] This consists in the development of chlorite and epidote as well as pyrite, from dark silicates, and the breaking down of feldspar to quartz, chlorite, and epidote.

Mineral Deposits formed at the Surface by Hot Waters (61). — At or near the surface mineral deposits may be formed by hot springs, but they are not usually of economic importance.

Such springs may deposit earthy carbonates as sinter, and silica as opal or chalcedony. Ore minerals developed under these conditions in crystallized form are stibnite, marcasite, and cinnabar, but other sulphides have been detected by chemical means. Calcite, fluorite, barite, and celestite may also develop.

According to what has been said above there is a somewhat continuous series of deposits from the deepest to the higher and cooler zones, the mineral combinations gradually changing from those of magmatic and contact-metamorphic conditions, to those known to exist in surface hot springs.

Formation of Cavities. — The deposition of ores in the rocks is greatly facilitated by the presence of cavities along which the ore-bearing solutions freely pass, and consequently a great many ore deposits occur in such spaces. There are a number of different ways in which cavities may be formed in rocks. The percolation of surface water through certain ones, such as limestones, often results in the formation of solution cavities,these in many instances attaining the size of veritable caverns; a soluble rock may contain more or less insoluble material, such as clay or chert, which collapses when the surrounding rock is dissolved, and partly fills the cave thus formed. At times the more resistant parts are so bound together that they remain in their original position, forming a porous mass, in the cavities of which mineral matter is later deposited.

Dynamic disturbances produce cavities of variable extent in many different rocks. These range from microscopic cracks, like the rift planes of granite, to enormous faults of great depth and linear extent, and include the joint planes so common in the rocks of almost all regions. Fault fissures form one of the most important types of passageways for ore-bearing solutions. They are often irregular, branching, and partly filled by fault breccia, caused by the breaking of the rock during the movement along the fault plane. A third important group of cavities in the rocks are those resulting from shrinkage of the mass, which may be due to (1) shrinkage during cooling, as in igneous rocks; (2) shrinkage during certain forms of replacement. For example, the change of carbonate of lime to dolomite is accompanied by a shrinkage of the mass, which renders the dolomite more porous than the original rock; and in the alteration of siderite to limonite there is a shrinkage of fully 20 per cent (25). A fourth type of channelway for the passage of underground water is the contact plane between two quite different kinds of rock, one of them fairly dense and impervious.

Deposition of Ore in Open Cavities. — Open cavities may, according to general belief, exist to a depth of many thousands of feet below the surface. If rock pressure alone were active, they could not theoretically exist below the zone of fracture, but it seems probable that hydrostatic pressure due to gravity may to some extent counteract rock pressure.

There is evidence to show that some large cavities must have existed at great depths, and here it is supposed that the force of crystallization has been sufficient to force the walls apart. Becker and Day have demonstrated the actual existence of such a force,[1] but Lindgren points out that it seems scarcely possible to attribute such power to it as would be necessary to force deep-seated crevices apart to form room for the crystals, and moreover that it would "seem impossible that under these conditions comb structure and coarsely, even-grained quartz could be produced." Graton[2] suggests that the crevices formed below the zone of fracture have been opened by the pressure of solutions forced out of the cooling magma.

Precipitation of Metals from Solution. — In some cases the metalliferous and other minerals found in ore deposits have no doubt been taken into solution by surface waters, and precipitated at no great depths; but in the majority of instances the metals were taken into solution at some point considerably below the piont of precipitation, where heat and pressure were evidently high. The deposition of the metals may then have been due to several causes, such as the mingling of waters, resulting in chemical reactions, contact of the solution with reducing agents such as carbon or ferrous sulphate, decrease in temperature and pressure, or where the precipitation occurs near the surface, by oxidation.

As has been pointed out by Lindgren (61) the physical conditions during deposition, especially temperature and pressure, are of great importance in determining the mineral association in ores formed by deposition from solution.

Certain minerals, for example, are very stable under high pressure and temperature, and could not therefore exist under conditions prevailing near the surface. That is to say, that the different minerals have their " critical level," above or below which they cannot form or exist. Other minerals are termed " persistent minerals," because they have a large interval of existence.[1]

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[1] Proc. Wash. Acad. Sci., VII: 283.

[2] U. S. Geol. Surv., Bulletin 293.

The conditions under which different ore minerals, as well as some others, may exist are given in the following table (p. 326) compiled by Lindgren (61).

Other Causes of Precipitation. — Other conditions may, however, operate to cause precipitation, for, as shown by Sullivan (86), the natural silicates have the power of precipitating metals from solutions of salts, "while at the same time the bases of the silicates are dissolved in quantities nearly equivalent to the precipitated metals." The bases which most commonly replace metals in such a process are potassium, sodium, magnesium, and calcium, and the metals are precipitated as hydroxides or basic salts. Cupric sulphide, for example, is precipitated as a basic cupric sulphate similar to brochantite or langite.

The same investigator (87) has also found that when a solution of ferric sulphate is passed through a Pasteur filter, 18 per cent of the iron is held in the tube. Repeated passage of the same solution caused the retention of additional quantities of the same metal. The explanation advanced is that hydrolysis has produced a colloid form of the iron oxide, which is caught in the pores of the porcelain. The experiment is highly suggestive and indicates that metalliferous solutions in passing through porous rocks may be robbed of some of their metallic contents by a similar process.

Some fifty years ago not a few geologists, prominent among them De la Beche, advocated the theory of ore precipitation by galvanic action (20, 35), and a number of experiments were made attempting to prove the existence of such action; now little weight is attached to this theory.

More recently Gillette (39) has expressed the view that osmotic pressure is an important factor in ore deposition, aiding to spread the dissolved metals through the water in the rocks, toward centers of crystallization.

Replacement, or Metasomatism (59*b*). — It is a well-known fact that under favorable conditions mineral-bearing solutions may attack the minerals of the rocks which they penetrate, dissolving them wholly or in part, and depositing some of the original burden

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[1] A. Grubenmann, Die Kristallinen Schiefer, Berlin, 1904, p. 55.

Minerals formed in Ore Deposits under Varying Conditions

Minerals	Igneous Condition	Pegmatitic Conditions	Contact-metamorphic Conditions	Deeper Vein Zone	Middle and Upper Vein Zone	Lower Ground-water Zone (Zone of Sulphide Enrichment)	Upper (Oxidizing) Ground-water Zone
Pyrite	* ?	* ?	*	*	*	*	
Chalcopyrite	*	*	*	*	*	*	
Bornite		*	*	*	*	*	
Arsenopyrite		*	*	*	*		
Galena			*	*	*	*	
Zincblende		* ?	*	*	*		
Molybdenite		*	*	*	*		
Gold	*	*	*	*	*	*	*
Quarts	*	*	*	*	*	* ?	
Calcite			*	*	*	*	
Fluorite	*	*	*	*	*		
Rutile	*	*	*	*	*		
Epidote			*		*		
Muscovite	*	*	*	*			
Sericite				*	*		
Pyrrhotite	*	*	*	*			
Ilmenite	*	* ?	*	*			
Magnetite	*	*	*	*			
Specularite		*	*	*			*
Spinell	*	*	*	*			
Corundum	*	*	*				
Cassiterite	*	*	*	*			
Anorthite	*	*	*				
Albite	*	*	*	*			
Garnet	*	*	*	*			
Andalusite		*	*				
Staurolite			*				
Ilvaite			*				
Tremolite			*	*			
Hornblende	*	*	*	*			
Diopside	*	*	*	*			
Vesuvianite			*				
Wollastonite			*				
Titanite	*	*	*				
Scapolite		*	*	*			
Tourmaline	*	*	*	*			
Topaz	*	*	*	*			
Apatite	*	*	*	*			
Barite				*	*		
Dolomite			* ?	*	*		
Siderite				*	*		
Cinnabar				*	*		
Marcasite					*		
Tetrahedrite					*		
Pyrargyrite					*	*	
Stephanite					* ?	*	
Polybasite					* ?	*	
Argentite					*	*	
Stibnite					*		
Tellurides				*	*		
Chlorite					*		
Adularia				* ?	*		
Celestite					*		
Opal and Chalcedony					*	*	
Kaolin						*	*
Chalcocite				* ?	* ?	*	
Covellite						*	
Limonite							*
Pyrolusite							*
Cuprite							*
Copper							*
Silver					*	*	*
Cerargyrite							*
Carbonates Sulphates Silicates Arsenates Phosphates } of Pb, Cu, Zn.							*
Soda-lime feldspars	*	*	*				
Orthoclase	*	*	*				
Zeolites		*				* ?	

in place of the material removed. This replacement, termed "metasomatism," is an important factor in the formation of many ore deposits, and may involve a total or partial loss of certain constituents of the rock attacked and a gain of others, even to the extent of introduction of entirely new compounds and elements. The change takes place molecule by molecule, a grain of vein material being deposited for each grain of replaced rock dissolved. The ore-bearing solutions penetrate the rock first along the smallest cracks, and then work their way into the individual mineral grains along their cleavage planes, until they finally permeate the entire mass (Figs. 112, 113, and 114).

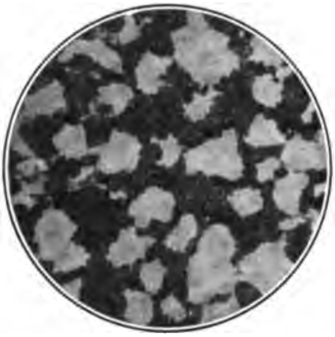

FIG. 112. — Photo-micrograph of a section of quartz conglomerate, showing replacement of quartz (white), by pyrite (black), × 25 diam. (*After Smyth, Amer. Jour. Sci., XIX*, 1905.)

Metasomatic processes show great variety, and are not confined to one kind of rock or mineral. In its simplest form the result of metasomatism may often be seen in fossiliferous rocks, where organic remains have been replaced by common mineral compounds, as in the replacement of the lime carbonate of corals by quartz, or the replacement of molluscan shells by pyrite. From such simple conditions there is every gradation to the complete replacement of extensive areas of rock by ore, or to the extensive operation of metasomatism along the walls of fissure veins. In most cases the changes are believed to be due to the action of underground water; but in some instances it seems probable that the processes of pneumatolysis (*q.v.*) were involved. Replacement is no doubt accomplished

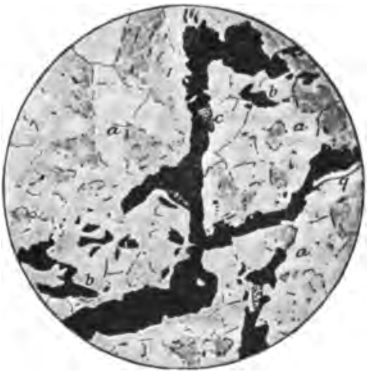

FIG. 113. — Replacement vein in syenite rock, War Eagle Mine, Rossland, B. C. (*a*) granular orthoclase with a little sericite; (*b*) secondary biotite; (*q*) secondary quartz; (*c*) chlorite; *black*, secondary pyrrhotite. (*After Lindgren, Amer. Inst. Min. Engrs., Trans. XXX.*)

in some cases by cold waters; but in many instances high temperature, pressure, and concentration seem to have been present, especially in the case of ore deposits in fissure veins. It is rarely possible, without examination of a thin section with the microscope, to decide whether minerals present are due to replacement or to simple interstitial filling.

Some minerals are more easily replaceable than others, consequently the rocks in which such predominate might be more widely affected than others. (See Butte, Montana, and Clifton, Arizona, under Copper.)

The theory of metasomatism was first applied in America by Pumpelly, in 1871, in explanation of the copper deposits of Michigan; but the ore bodies of Leadville, Colorado, and Eureka, Nevada, were the first large deposits whose origin was explained by it. Since then the great importance of metasomatism has been widely recognized, and it has become evident that preëxisting cavities are not necessary to the formation of ore bodies.

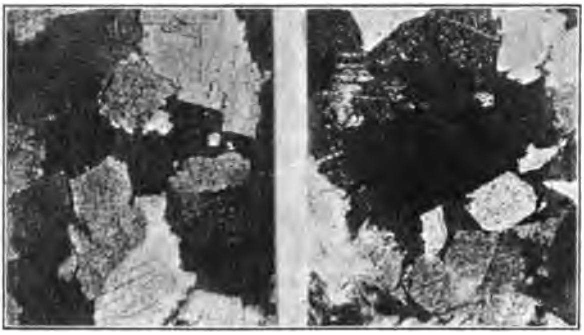

Fig. 114. — Photo-micrographs of thin sections of sulphide ore from Austinville, Va., mines. × 20 diam. crossed nicols. Shows crystalline granular dolomitic limestone, and the filling of fine cracks accompanied by replacement of limestone grains along crystallographic directions by the sulphides. Very dark irregular areas in center represent sulphides. Reëntrant angles along margins of the sulphides and the spider-like arrangement of the sulphide areas as a whole are well shown. (*After Watson, Va. Geol. Surv., Bull. I.*)

Forms of Ore Bodies (31). — Ore bodies vary greatly in their form, and this character has at times been used as a basis of classification by some writers; but the more modern tendency is to use genetic characters instead, making shape of secondary importance in the grouping. Certain forms of ore bodies are so numerous as to deserve special mention.

Fissure Veins (30, 38, 45, 59*a*, 74, 99). — A fissure vein may be defined (59*b*) as a tabular mineral mass occupying or closely associated with a fracture or set of fractures in the inclosing rock, and formed either by filling of the fissures as well as pores in the wall rock, or by replacement of the latter (metasomatism). When the vein is simply the result of fissure filling, the ore and gangue minerals are often deposited in successive layers on the walls of the fissure (Rico, Colorado), the width of the vein depending on the width of the fissure and the boundaries of the ore mass being sharp. In most cases, however, the ore-bearing solutions have entered the wall rock and either filled its pores or replaced it to some extent, thus giving the vein an indefinite boundary. Therefore the width of the fissures does not necessarily stand in any direct relation to the width of the vein (99) (Butte, Montana). The term *vein material* is best used to apply to the aggregate of materials which make up the ore body. *Vein stone*, though sometimes used, is less desirable (Emmons).

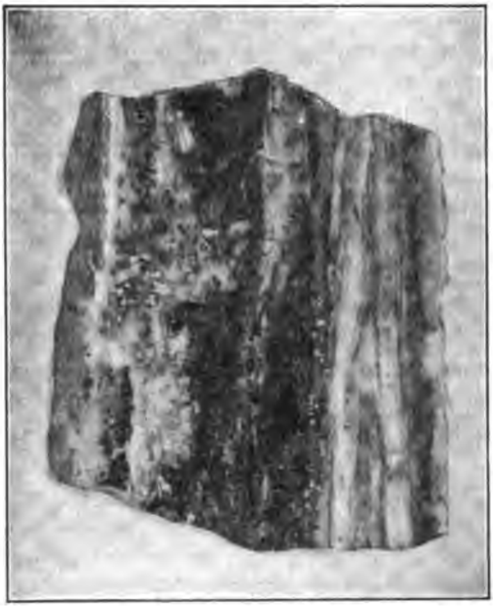

FIG. 115. — Section of vein in Enterprise mine, Rico, Colo. The right side shows later banding due to reopening of the fissure. (*After Ransome, U. S. Geol. Surv., 22d Ann. Rept., II.*)

Veins formed by the simple filling of a fissure often show a banded structure of varying regularity termed *crustification*[1] by Posepny (Fig. 115), which may sometimes be brecciated by later movements along the fissure. Secondary bands may be formed after reopening of the fissures (Fig. 115), and such a movement may cause brecciation of the vein material. This later movement may sometimes form a layer of soft, clayey material, known as *gouge* or *selvage*, between the vein and the country rock. Where the fissure has not been completely filled, thus leaving a central space into which the crystals of gangue project, a *comb structure* is formed. The bands in a filled fissure may consist of gangue and ore alternating, or of different ores. Among the commonest ore minerals seen in these fissure veins are pyrite, chalcopyrite, galena, blende, and sulphides of silver. Some regions afford especially fine examples of banded veins, notably those of Grass Valley, California, and Rico, Colorado. Abroad the mines of Freiberg, Saxony, and Clausthal, Prussia, also often yield magnificent specimens. Even in a single vein the ore may follow certain streaks which are termed *shoots* (*q.v.*) or again it may be restricted to pockets of great richness, which are known as *bonanzas*.

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[1] The replacement of certain layers only in a bed of stratified rock may also produce a banded structure.

In some veins the friction breccia or dragged in fragments of the country rock form a considerable portion of the vein filling, and the ore has been deposited in layers around these fragments.

Fissure veins in which metasomatic action has predominated show great irregularity of width and an absence of well-defined boundaries; they also lack as a rule the symmetrical banding and the breccias cemented by vein material. There are all gradations between these two types of fissure veins; and even in a single vein simple filling may occur in one part and replacement in another.

Veins often split or intersect, and at the point of intersection or splitting the ore is apt to be richer. There are other reasons for variations in richness, among the most important being the character of the wall rocks, some kinds being more easily replaceable or more porous than others. Their physical character will moreover exercise considerable influence on the shape and size of the fissure. Tough rocks like gneiss, for example, give a clean-cut fissure, but in brittle rock the fissure is apt to split frequently, and therefore a vein may be workable in one kind of rock, but becomes worthless when passing to another, since the profuse branching interferes with economical mining (Fig. 116). A dike may also cause local irregu-

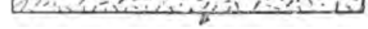

FIG. 116. — Section showing change in character of vein passing from gneiss (*g*) to quartz porphyry (*p*). (*After Beck, Lehre von der Erzlagerstätten:* 135.)

larities, and in a given region the fissures not uncommonly show great variation in their direction. Thus at Butte, Montana (*q.v.*), east-west veins predominate, while in the Silverton district of Colorado they cut the rocks in all directions, but the majority show a north of east trend. In the Monte Cristo, Washington, district the veins with northeast trend are predominant (Fig. 117).

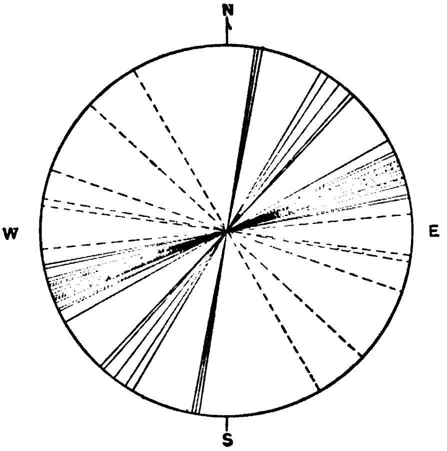

FIG. 117. — Tabulation of strikes of principal veins in Monte Cristo, Wash., district. (*After Spurr, U. S. Geol. Surv., 22d Ann. Rept., II.*)

Fissures veins vary considerably in their width, swelling at some points and pinching or narrowing at others. They also at times show lateral enrichment (Ouray, Colorado); for instance, where the ore cuts through stratified beds, into which the ore-bearing solutions have spread out laterally along the planes of stratification or other planes. It has been noticed in some veins, especially those formed by replacement, that the filling varies with the wall rock, at times changing suddenly; but where the vein is formed wholly by the filling of an open fissure, the rock exerts no influence on the character of the ore (99). If the vein is inclined, the lower wall is spoken of as the *foot wall* and the upper one as the *hanging wall.*

Parallel fissures are not uncommon, but the several veins do not necessarily show an equal degree of richness. Where the vein is of composite character, — that is, consisting of closely spaced parallel fissures accompanied sometimes by a mineralization of the intervening rock, — it is termed a *lode.*

The term *vein systems* is suggested for a larger assemblage of vein fissures, which may include several lodes.

Subordinate fractures, such as little veins, that cross the material included within the vein walls, are called *veinlets* or *stringers.*

The top of the vein is called the *apex,* and is occasionally traceable for a long distance. It does not necessarily outcrop at the surface.

Linked veins represent a type in which the parallel fissures are connected by diagonal ones (Fig. 118), giving a series resembling the links of a chain.

Gash veins are a special type of fissure vein, formed by the enlargement of joint planes and sometimes bedding planes. They are characteristic of the upper Mississippi Valley lead and zinc region, but are usually of limited extent and local importance. In the simplest form they are a vertical fissure, but develop into types shown in Fig. 119.

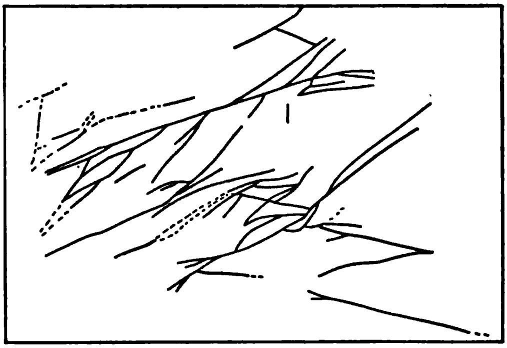

FIG. 118. — Linked veins. (*After Ordonez.*)

Bedded vein. — This term is sometimes applied to a deposit conforming with the bedding. It is also called *bedded deposit.* Among miners the term *blanket vein* is commonly applied to any nearly flat deposit.

Filling of Fissure Veins (45). — The manner in which fissure veins have been filled, and the source of the metals which they contain, formed a most fruitful subject of discussion among the earlier geologists. The several theories advanced and the arguments for and against them are well set forth in Kemp's paper (45), and it may simply be said here that most geologists now believe that the primary deposition of ores in fissure-vein deposits was accomplished by solutions ascending along the fissures, which sometimes spread out into the wall rocks, to a variable distance.

Other Forms of Ore Deposits. — *Chimney* is a term applied to ore bodies which are rudely circular or elliptical in horizontal cross section, but may have great vertical extent. A *stock* is a somewhat similarly shaped ore body, but of greater irregularity of outline. *Fahlband* is a term originally used by German miners to indicate certain bands of schistose rocks impregnated with finely divided sulphides, but not always rich enough to work. It is occasionally used in this country. *Impregnation* is a term indicating the occur-

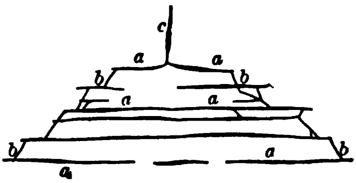

FIG. 119. — Gash vein with associated "flats" (*a*) and "pitches" (*b*). Wisconsin zinc region. (*After Grant, Wis. Geol. and Nat. Hist. Surv., Bull. IX.*)

rence of minerals in a finely disseminated condition in rocks, either as a filling of open spaces or as a replacement of certain minerals. *Disseminated deposits* (Fig. 120) is regarded as a better term by some. *Contact-metamorphic deposits,* as now understood, represent ore bodies formed along the contact of a mass of igneous and sedimentary rock (usually calcareous), the ore having been derived wholly or in part from the intrusive mass (Clifton, Arizona, in part).[1] *Ore channels* include those ore bodies formed along some path which the mineral solutions could easily follow, as the boundary between two different kinds of rock (Mercur, Utah). *Bedded deposits,* found parallel with the stratification of sedimentary rocks, and sometimes of contemporaneous origin (Clinton iron ore).

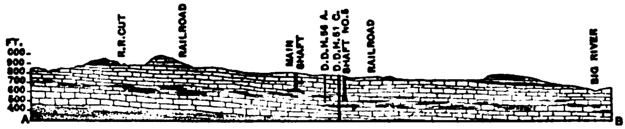

FIG. 120. — Section at Bonne Terre, Mo., showing ore disseminated through limestone.

Ore shoots (43, 67, 65, 104). — Few ore deposits are of uniform character throughout, indeed the occurrence of pay ore is apt to be more or less irregular, the richer material being often somewhat restricted in its occurrence. These richer portions, if small, may be called *nests*, or *pockets*, but if large, the term *ore shoot* is commonly applied to them. According to some authors the ore shoot includes only the richer portion of the workable ore. (Van Hise.)

Other writers, among them Emmons, Lindgren and Ransome, employ the

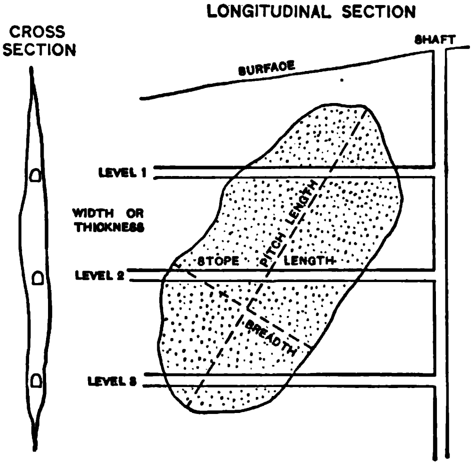

FIG. 121. — Sketch showing dimensions of an ore shoot. (*After Lindgren and Ransome.*)

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[1] If the term *contact-metamorphic deposit* is used for this type, it would not necessarily conflict with the term *contact deposit*, applied to any ore body occurring along the boundary between two formations or two kinds of rock.

term ore shoot or pay shoot to signify the workable part of a lode or similar deposit.

Ore shoots are commonly of irregular shape, and usually steep dip, although they may be nearly horizontal.

According to Emmons the ore shoot, as a rule, has a longer axis that forms a large angle with a horizontal plane. This longer axis may be called the *pitch length*,[1] and the horizontal dimensions along the level the *stope length*. Ore shoots are evidently caused by varying chemical and physical conditions in different parts of the deposit, at the time the ore was formed, thus causing a more abundant precipitation of the ore minerals in certain parts of the deposit. More abundant fissuring, or brecciation, in certain parts of the rock may operate to promote deposition in those parts of the mass; clay walls may be influencing factors in guiding the ore solutions towards certain spots; or intersecting fissures may permit the mingling of reacting solutions, thereby bringing about more abundant precipitation of ore at these crossing points. The existence of fissures in certain parts of the ore body might produce additional deposition in those parts, by serving as a guiding channel to either ascending or descending enriching solutions.

The examples cited above apply especially to epigenetic deposits; but if the term *ore shoot* is used in its broadest sense, one might reasonably include ore masses formed by magmatic segregation.

Several attempts have been made to classify ore shoots, all of them being on a genetic basis. Thus Van Hise [2] divides them into three groups as follows: (*A*) those explained largely by structural features; (*B*) those formed by the influence of wall rocks; and (*C*) those formed by secondary concentration by descending waters.

Irving (43) has classified them as (1) shoots of variation, or those which vary from the inclosing material only in relative richness of the ore; and (2) shoots of occurrence, or those which occur in isolated positions with no other ore of any kind about them.

Winchell [3] makes a division into (1) paragenetic shoots, or those developed mostly at the time of the original formation of the ore deposit inclosing them; and (2) postgenetic shoots, or shoots developed mostly after the original formation of the inclosing ore deposit.

Secondary Changes in Ore Deposits (26, 55, 66, 70, 73, 78, 94).— Ore deposits are often changed in their upper parts, and sometimes to a considerable depth, by weathering agents, while the lower-lying portions, below the ground-water level, are often enriched by secondary processes.

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[1] Lindgren and Ransome.

[2] Amer. Inst. Min. Engrs., Trans. XXX: 27.

[3] Econ. Geol., III: 425, 1908.

The two zones each show a somewhat characteristic set of compounds. Thus in the weathered zones we find sulphates, carbonates, silicates, oxides, chlorides, arsenates and native metals; while in the lower zone the compounds are sulphides, tellurides, arsenides, and antimonides.

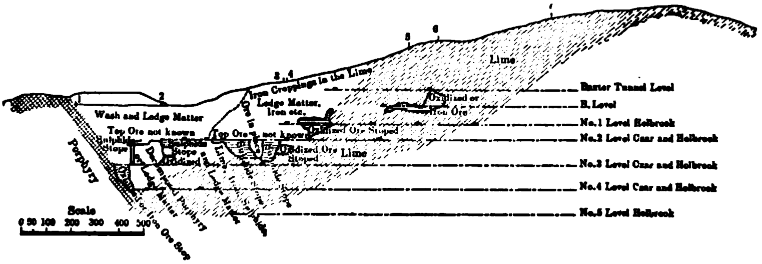

FIG. 122. — Section through Copper Queen Mine, Bisbee, Ariz., showing variable depth of weathering. (*After Douglas, Amer. Inst. Min. Engrs., Trans. XXIX.*)

Weathering may disguise the true character of an ore body most effectually. For example, the ore found in the outcrop may be a gold ore, and mills are sometimes erected and operated for a period on such ore, without any suspicion that beneath there may be great bodies of copper or lead sulphides. Such a change has been found at Bingham, Utah; Ely, Nevada; or Mount Morgan, Australia. The last has been one of the world's greatest gold mines, but is now producing copper from its lowest levels. In other cases, the base metals may all have been leached out of the upper part of the ore body, and too little gold remains in the gossan to make it profitable. Butte, Montana, is a well-known example of this, for the nearly barren outcrops gave little clew to the great secondary ore bodies lying below, and which might never have been discovered but for the presence of another system of closely associated veins carrying silver.

Weathering or Superficial Alteration (66). — Nearly all minerals are attacked by the weathering agents, but the metallic minerals are more easily and more profoundly affected than the non-metallic ones.

This weathering process involves both chemical and physical changes similar to the decay and disintegration of common rocks, but in ore bodies the great number of minerals involved, including many with a metallic base, give rise to a large number of intricate chemical reactions.

As a result of weathering worthless minerals may be removed, leaving the weathered part more porous, and this may increase the richness, because we have a greater quantity of metals per ton of rock.

Since many of the metalliferous minerals are more easily decomposed than the common rock-forming minerals, the alteration in an ore body is more rapid and extends to a greater depth than in the country rock. There is, however, a marked variation in the rate at which the different ore minerals decay, and this variation exists even in a single group like the sulphides, in which the order or rate of decomposition is arsenopyrite, pyrite, chalcopyrite, blende, galena, chalcocite, and tetrahedrite.

The weathered part of the ore body, so often strongly stained by limonite, is known as the *gossan,* or iron hat (French, *chapeau-de-fer;* German, *eisener hut*).

The first chemical changes in the weathering of an ore body are oxidation or hydration, or both; and these, together with other changes, produce many soluble compounds, which can be, and often are, leached out of the gossan by percolating waters. An example of oxidation is the alteration of pyrite to ferrous and ferric sulphate, and by hydration and further oxidation to limonite. Chalcopyrite oxidizes to copper sulphate and by hydration and further oxidation to copper carbonate, silicate, or oxide. We see therefore that the first change in each of the above cases is the same, sulphates being formed from sulphides; but that the later changes are different, the iron sulphate changing to hydrous oxide, while the copper forms a different set of compounds.

Many of the sulphates formed may be removed in solution, but not a few of the new compounds produced, such as sulphates, chlorides, carbonates, silicates, or even native metals, remain mixed with the limonite in the weathered zone.

The porosity of the gossan is sometimes due to leaching, sometimes to shrinkage, as when siderite or pyrite changes to limonite. Hydration, on the contrary, causes expansion.

The depth of weathering depends on topographic conditions, chemical nature and porosity of the deposits, climate, etc.; but in any event it is liable to vary in the same deposit, owing to variation in the permeability of different parts of the mass (Fig. 122). In Arizona many copper deposits have been changed from sulphides to carbonates, to a depth ranging from 100 to 700 feet; the oxidized ores of the Appalachian region average about 100 feet in depth; while those of the Rocky Mountain area range from 50 to 700 or more feet in depth.

The ferric sulphate produced by the weathering of pyrite is a most important factor in the alteration of ore deposits. When formed it attacks pyrite and other sulphides, converting them into sulphates, at the same time being itself reduced to ferrous sulphate, which is in part changed to limonite and sulphuric acid. That portion remaining unreduced begins anew the scale of change. Ferric sulphate is thus the main agent by which the sulphides are dissolved. Moreover, it also acts as a solvent of free gold.

All the metallic contents are not, however, leached from the gossan, for some minerals are either difficult to dissolve or remain unattacked. Thus in some cases the leaching produces an enrichment by the removal of worthless constituents and a consequent increase per ton of valuable minerals. The soluble compounds produced by weathering are often carried downward by percolating water and deposited in an irregular zone between the gossan and the unweathered ore below, as in some copper deposits where there is found a rich zone of black copper between the gossan and unaltered sulphides.

Secondary Deposition below Ground-water Level. — In many ore bodies, rich masses of ore occur below the oxidized zone, which microscopic investigation has shown to be of secondary character. The secondary deposition is most often seen in gold, silver, copper, lead, and zinc ores, and is due to the downward migration of the products of weathering and their redeposition below the water level.

If the body of unaltered sulphides below is broken by fissures, the solutions containing the various metallic sulphates and sulphuric acid will enter them, penetrating at times to considerable depths. Reactions may then take place between the dissolved sulphates and the sulphides present, resulting in the precipitation of new sulphides on the walls of the fracture, and forming rich patches of ore known as bonanzas (73, 94). The association of these fractures formed after the primary sulphides is an important character of value to the mining engineer, and from what has been said above, it can be seen what an important rôle sulphides play in the secondary enrichment process. It has been noticed, however, that pyrite is not the only reducing and precipitating agent in ore deposits. Carbon is a strong reducer, and other minerals also exert a variable influence (42). (See deposition of lead and zinc in Wisconsin and Ozark region, Chapter XVII.)

With continued erosion of the surface, there is a continuous downward removal, and the lower-lying ores become more and more enriched; but the secondary enrichment process is affected by a number of factors.

Thus if erosion is more rapid than oxidation, the body of sulphides may extend to the surface, for even if any gossan forms it is rapidly removed. On the other hand, if oxidation is more rapid than erosion, a gossan develops.

Both weathering and secondary enrichment are therefore dependent on the physical structure and solubility of the rock, temperature (and indirectly topography), quantity of water, and length of time.

Reactions Involved. — One or two cases may be cited which will give in greater detail the changes referred to above.

If, for example, we have an ore containing pyrite, galena, and sphalerite in limestone the following changes may take place: —

The sphalerite, galena, and pyrite may be changed to sulphates, thus: —

$$ZnS + 4O = ZnSO_4, \text{ or}$$
$$PbS + 4O = PbSO_4.$$

1. The sulphates may react with the limestone: —

$$ZnSO_4 + CaCO_3 + 2H_2O = ZnCO_3 + CaSO_4, 2H_2O,$$
$$PbSO_4 + CaCO_3 + 2H_2O = PbCO_3 + CaSO_4, 2H_2O.$$

2. The sulphates or some carbonates may be carried down below water level into the zone of unaltered sulphides, where the following reactions occur: —

$$PbSO_4 + FeS_2 + O_2 = PbS + FeSO_4 + SO_2,$$
$$PbCO_3 + FeS_2 + O_2 = PbS + FeCO_3 + SO_2, \text{ or}$$
$$PbSO_4 + ZnS = PbS + ZnSO_4,$$
$$PbCO_3 + ZnS = PbS + ZnCO_3.$$

These zinc compounds, being soluble, might be carried down still farther and there react with iron sulphides, as follows: —

$$ZnSO_4 + FeS_2 + 2O = ZnS + FeSO_4 + SO_2, \text{ also}$$
$$ZnCO_3 + FeS_2 + 2O = ZnS + FeCO_3 + SO_2.$$

Second Case. — In an ore consisting of a mixture of chalcopyrite ($CuFeS_2$) and pyrite (FeS_2), the following changes might take place on weathering: —

$$CuFeS_2 + 8O = CuSO_4 + FeSO_4, \text{ and}$$
$$FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4.$$

This last equation involves intermediate stages in which S, H_2S, and SO_2 may be formed.

The $FeSO_4$ gives $Fe_2(SO_4)_3$ which is easily decomposed to a basic sulphate, free hydrates, and free acid.

If the pyrite is cupriferous, the H_2SO_4 will oxidize more of it.

The $Fe_2(SO_4)_3$ may attack pyrite and other sulphides, changing them to sulphates and being itself reduced to $FeSO_4$; as

$$5Fe_2(SO_4)_3 + Cu_2S + 4H_2O = 2CuSO_4 + 10FeSO_4 + 4H_2SO_4.$$

This cycle of reactions will probably continue until all of the sulphides exposed to oxidation have been changed to oxysalts, and most of the iron changed to limonite. The $CuSO_4$ formed in the zone of weathering may by further reactions develop (1) minerals characteristic of the oxidized zone, or (2) it may be carried in solution down into the sulphide zone, and there be reduced to sulphides. As illustrative of the first class we have: —

$$2\,CuSO_4 + 2\,H_2Ca(CO_3)_2 = CuCO_3\,(CuOH)_2 + 3\,CO_2 + 2\,CaSO_4 + H_2O,$$
$$3\,CuSO_4 + 3\,H_2Ca(CO_3)_2 = 2\,CuCO_3\,(CuOH)_2 + 3\,CaSO_4 + 4\,CO_2 + 2\,H_2O,$$
$$2\,CuSO_4 + 2\,FeSO_4 + H_2O = Cu_2O + Fe_2(SO_4)_3 + H_2SO_4,$$
$$Cu_2O + H_2SO_4 = Cu + CuSO_4 + H_2O,$$
$$CuSO_4 + H_2Ca(CO_3)_2 + H_4SiO_4 = CuO,\ H_4SiO_4 + CaSO + H_2O + CO_2.$$

In the second class, where $CuSO_4$ is carried downward into the sulphide body, the reactions given below no doubt occur: —

$$CuSO_4 + CuFeS_2 = 2\,CuS + FeSO_4, \text{ or}$$
$$2\,CuSO_4 + CuFeS_2 + SO_2 + 2\,H_2O = Cu_2S + CuS + FeSO_4 + 2\,H_2SO_4, \text{ or}$$
$$CuSO_4 + 2\,FeS_2 + 2\,O = CuFeS_2 + FeSO_4 + SO_2, \text{ or}$$
$$Cu_3FeS_3 + CuSO_4 + O_2 = 2\,Cu_2S + FeSO_4 + SO_2, \text{ or}$$
$$CuSO_4 + 2\,CuFeS_2 + O_2 = Cu_3FeS_3 + FeSO_4 + SO_2.$$

Value of Ores. — The terms *rich* and *poor*, as applied to ores, are used with great frequency, although most indefinite and often meaningless. Under very favorable conditions it is possible to profitably work an ore of given value at one locality, while if found under other less favorable conditions at another point it might be almost worthless.

Those who have not given special study to ore deposits often fail to realize that in the majority of ores the percentage of metal contained in the ore falls considerably below the theoretic percentage of the metallic contents in the ore-bearing minerals, due of course to the presence of a greater or less quantity of gangue minerals which tend to dilute the metallic values of the vein. Many low-grade lead ores are profitably mined because their gold and silver contents more than pay the cost of metallurgical treatment. In many cases the metallic contents of the ore is increased by mechanical concentration or by roasting (in the case of sulphides), or both, before the ore is smelted.

Allowable Minimum of Metal in an Ore (52). — Iron ores are of little value, wherever they may be located, unless they contain at least 30 per cent of iron when charged into the furnace.

Copper has an average minimum of about 2 per cent, but the Lake Superior ores, because of their peculiar characteristics, can be operated on a lower percentage. In the case of these low-grade ores the metallic contents are raised by mechanical concentration or roasting, or both, before entering the furnace.

Lead. — In southeastern Missouri lead ores are profitably mined when carrying as little as 5 to 10 per cent metal, but the concentration raises the percentage up to 65 or 70 per cent.

Zinc ores on entering furnace should have a minimum of 25 to 30 per cent zinc, but the contents are sometimes raised to 60 or more per cent by concentration.

Gold and Silver. — The metallic contents of these ores are expressed, not in percentages, but in troy ounces per ton, a troy ounce in a ton being $\frac{1}{300}$ per cent. The market value of silver is, in round numbers, 50–60 cents per ounce, while gold in round numbers is figured at $20 per ounce.

Silver rarely occurs alone, and the ore may be treated primarily for its associated lead and copper.

In the base ores there should be enough silver to yield a minimum of $5 or 10 ounces in the resulting ton of copper, to make its extraction profitable. If now in a 5 per cent copper ore 20 tons of ore are concentrated to 1 ton of pig copper (or 21 tons, allowing for losses), it follows that we need 10 ounces of silver, in 21 tons of ore, or a minimum or $\frac{1}{2}$ ounce silver per ton, or $\frac{1}{600}$ per cent.

Under favorable conditions gold can be extracted down to $\frac{1}{10}$ ounce per ton or $\frac{1}{3000}$ per cent. It usually runs from $\frac{1}{2}$ to 1 ounce.

In some copper or lead ores the saving of even $\frac{1}{20}$ ounce gold may be an object. In gravels, a gold content of as low as 7 to 10 cents per cubic yard ($\frac{1}{200}$ to $\frac{1}{300}$ ounce) may be saved.

Tin. — For this metal the crude ore commonly ranges from 1.5 to 3 per cent, but by concentration it can be raised to 70 per cent.

Nickel should reach 2 to 5 per cent in the crude ore.

Platinum. — Owing to the scarcity of this metal, few figures are available, but in Russia placers are worked which carry $\frac{1}{40}$ ounce per cubic yard, which is the equivalent of $\frac{1}{60}$ ounce per ton or 5.5 hundred-thousandths per cent.

Manganese ore must yield 50 per cent manganese to be marketable, although if iron is present it may drop to 40 per cent.

Chromium ore should carry 40 per cent of the metal.

Classification of Ore Deposits. — Many attempts have been made to develop a suitable classification of ore deposits, and many schemes have been suggested (46). These are usually based either on form, mineral contents, or mode of origin. The first is perhaps the most practical from the miner's standpoint, the second is undesirable because several kinds of ore may often be found in the same ore body, while the third is the most scientific, and is of value to the mining geologist and engineer.

Those desiring to look into this phase of the subject in more detail are referred to the bibliography at the end of this chapter, especially the papers by Kemp (46), Posepny (68), Van Hise (2), and Vogt (13).

Only one classification is given here, viz. that of W. H. Weed, not because it is considered entirely satisfactory or especially simple, but because it embodies the results of the more modern studies of ore deposits and their genetic character.

CLASSIFICATION OF ORE DEPOSITS (AFTER WEED)

A. Igneous, magmatic segregation.
  (*a*) Siliceous.
    1. Masses, Aplitic masses. Ehrenberg, Shartash.
    2. Dikes, Beresite or Aplite. Berezovsk.
    3. Quartz veins. Alaska, Randsburg, Black Hills.
  (*b*) Basic.
    1. Peripheral masses. Copper, iron, nickel. (Sudbury, Ont.)
    2. Dikes, titaniferous iron. Adirondacks, Wyoming.
B. Igneous emanations. Deposits formed by gases above or near the critical point, *e.g.* 365° C. and 200 atmospheres for H_2O.
  (*a*) Contact-metamorphic deposits.
    1. Deposits confined to contact. Magnetite deposits (Hanover, N. Mex.), chalcopyrite deposits, Kristiania type, gold ores, Bannock, Ido., type.
    2. Deposits impregnating and replacing beds of contact zone. Chalcopyrite deposits, pyrrhotite ores, magnetite ores, Cananea type, gold tellurium ores, Elkhorn type, arsenopyrite ores, Similkameen type.
  (*b*) Veins closely allied to magmatic veins and to Division D.
    1. Cassiterite. Cornwall.
    2. Tourmaline copper. Sonora.
    3. Tourmaline gold. Helena, Mont., Minas Geraes, etc.
    4. Augite copper, etc. Tuscany.
C. Fumarolic deposits.
  (*a*) Metallic oxides, etc., in clefts in lava. No commercial importance. Copper, iron, etc.
D. Gas-aqueous or pneumato-hydato-genetic deposits, igneous emanations, or primitive water mingled with ground water.
  (*a*) Filling deposits.
    1. Fissure veins.
    2. Impregnation of porous rock.
    3. Cementation deposits of breccia.
  (*b*) Replacement deposits.
    1. Propylitic. Comstock.
    2. Sericitic kaolinic, calcitic, Copper silver, Silver lead. Clausthal. De Lamar, Ido.
    3. Silicic dolomitic, silver lead, Aspen.
    4. Silicic calcitic. Cinnabar, California.
    5. Sideritic silver lead. Cœur d'Alene, Slocan, Wood River.
    6. Biotitic gold copper. Rossland, Brit. Col.
    7. Fluoric gold tellurium. Cripple Creek, Colo.
    8. Zeolitic. Michigan copper ores.

Structure Types of Above

Fissure veins. (San Juan, Colo.)
Volcanic stocks, Nagyag. Cripple Creek.
Contact chimneys. Judith.
Dike replacements and impregnations.
Bedding or contact planes. Mercur.
Axes of folds, synclinal basins, anticlinal saddles. Bendigo, Elkhorn.

E. Meteoric waters. (Surface derived.)
  (*a*) Underground.
    1. Veins. (Wisconsin lead and zinc.)
    2. Replacements. Iron ores, Michigan; lead, zinc.
    3. Residual. Gossan iron ores, manganese deposits. (Virginia.)
  (*b*) Surficial.
    1. Chemical. Bog iron ores, sinters. Some bedded iron ores, etc. (Clinton ore.)
    2. Mechanical. Gold and tin placers.
F. Metamorphic deposits. Ores concentrated from older rocks by metamorphism, dynamo or regional.

Metallogenetic epochs. — The term metallogenetic epoch refers to a period of time during which a deposition of metals was taking place, and usually accompanied or immediately followed periods of igneous activity. This process has been active, during a number of periods in the past, as shown by the geologic records, and the available data for North America have recently been well summarized by Lindgren (62).

Pre-Cambrian Period. — The pre-Cambrian rocks, which underlie a number of extensive areas in the United States, include not only metamorphosed schists and gneisses, but also various types of intrusives, the characteristic metals being iron, copper, nickel, gold, and silver. Lead and zinc are less abundant than they are in the later periods, while quicksilver and antimony are rare.

The ilmenites and magnetites of the eastern states are chiefly of igneous origin, while the hematites of Lake Superior are partly igneous and partly sedimentary, but subsequently oxidized and concentrated by surface waters, a process which is believed to have gone on in pre-Cambrian times. The copper and nickel ores are associated with basic igneous rocks, some of these, as in Michigan, being of effusive nature. This copper concentration Lindgren suggests must have gone on in pre-Cambrian times, following the close of Keeweenawan (Algonkian) volcanic activity. Of similar age are the cobalt-silver veins of Ontario. The auriferous-quartz veins of the southern states, whose deposition followed that of granitic intrusions in schists, are also to be placed here, although some writers would date them later.

In the Cordilleran region the pre-Cambrian was productive of gold and copper deposits, which are found at many points from South Dakota and Wyoming to Arizona. These gold ores are usually lenticular quartz veins in schists, associated with such gangue minerals as tourmaline, garnet, etc. The copper ores often contain chalcopyrite, and form veins or irregular masses, which are probably of magmatic origin, and have been modified by dynamo-metamorphism. Sphalerite may accompany the chalcopyrite, but lead is almost entirely wanting.

Paleozoic. — During this time a number of granitic intrusions occurred from New York and New England northward to Quebec and Nova Scotia, and these were accompanied by the formation of some gold-quartz veins; but little metallization occurred in the West during this period.

Two periods of iron-ore formation occurred during Paleozoic time in the East. One of these was in the Silurian, when the persistent beds of low-grade Clinton hematite were formed; the other was during the Carboniferous, when the layers of carbonate blackband ores were deposited.

Mesozoic. — During the Triassic, small deposits of copper and iron ores were formed in the eastern states, along the contact of the trap sheets and sedimentary rocks. The deposits were in part veins and in part of contact-metamorphic character.

In the West important accumulations of ores were beginning, for during the Triassic there began a series of eruptions which continued through the Jurassic, the products of these being basic lavas which were extruded from California to Alaska. The metallization accompanying or following these yielded copper deposits, which include some of those found in California, British Columbia, and those of the Copper River region in Alaska.

Another important metallization epoch followed the intrusion of the great early Cretaceous quartz-monzonite or grano-diorite batholiths of the Pacific coast.

These injections were of vast extent, one batholith extending through California, and another from Washington up through British Columbia to Alaska, while other smaller masses occur in several of the western states. These intrusions were followed by intense metallization, mineral deposits being formed in abundance around the margin of the batholiths, as in the gold belt of California. Gold was the chief metal formed, with copper next. Along the Pacific coast, where there is little limestone in the intruded sediments, lead is rarely found, but in the interior (Nevada and Idaho) where limestones were present, lead and zinc both occur. Silver is everywhere present, but is rarely important unless associated with lead; arsenic and antimony are rare; and mercury is wanting in commercial quantities.

Early Tertiary. — About this time, perhaps a little earlier, or a little later, important concentrations of lead and zinc took place in the Mississippi Valley, but they appear to have been independent of igneous intrusions, and are thought by most geologists to represent the work of surface waters, the ultimate source of the metals being the pre-Cambrian rocks. This is questioned by Lindgren, who points out the scarcity of the lead and zinc in the rocks of that age, and also that there are transitional types between the normal ore deposits and certain lead-zinc deposits in Arkansas and Kentucky which resemble western vein types formed by hot waters.

At the close of the Cretaceous violent outbursts began along the eastern margin of the Cordilleran region, the magmas being of intermediate character and laccolithic form. They occur from British Columbia through Montana, Colorado, New Mexico, and eastern Arizona down into Mexico.

There ensued then another or third epoch of Cordilleran metallization, during which many contact-metamorphic deposits and veins were formed around the margins of the laccoliths. Gold and silver are the characteristic metals, with abundant lead and zinc, especially where the intrusions cut limestones. The latter may also show copper and iron along the contact. Arsenic and antimony are more common than they were in the earlier epochs, but mercury is still rare.

Late Tertiary. — After a period of mountain-making disturbances, uplift, warping, and dislocations, there were extruded a series of lava flows which spread over a large area in the far West, and are prominent in California, Washington, Oregon, Idaho, Colorado, Utah, Nevada, New Mexico, and Arizona. Andesites and rhyolites predominate. This was accompanied by a fifth metallization, whose characteristic metals are gold and silver, forming deposits often of great richness; lead and zinc are not abundant, except in limestone, and neither is copper. Tellurium and antimony are; not that they are absent in older metallizations, but the tellurium seems to be especially characteristic of this epoch. The metallic deposits seem to be somewhat restricted, occurring mainly near the foci of igneous activity.

Post-Pliocene. — There came finally an epoch of metallization at a late date, restricted, however, to the Pacific coast line, and characterized by the mercury deposits of the Pacific coast belt.

Cretaceous or Later Copper Epochs. — These, being of wide time range, cannot be included in the previous classes. They represent disseminations of copper in sandstone shales or conglomerates, and carry in most cases primary chalcocite with a little silver.

Summary. — The following table of Lindgren's summarizes the conditions for the western states: —

	PRINCIPAL METALS	PRINCIPAL ROCKS ASSOCIATED WITH DEPOSITS
1. Deposits of the pre-Cambrian period	Gold and copper . .	Granites Diorites, gabbro
2. Deposits of the early Mesozoic epoch . . .	Copper	Basalt, diabase Gabbro
3. Deposits of the late Mesozoic epoch	Gold	Granodiorite Quartz-monzonite
4. Deposits of the early Tertiary epoch	Gold, silver . . . Copper, lead, zinc .	Granodiorite Quartz-monzonite Monzonite
5. Deposits of the late Tertiary epoch	Gold, silver . . .	Andesite Rhyolite
6. Deposits of the Post-Pliocene epoch . . .	Quicksilver . . .	Basalt
7. Cretaceous or later concentrations in sedimentary rocks	Copper	Sandstone, shale Conglomerate

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CHAPTER XV

IRON ORES

IRON is an abundant constituent of the earth's crust, and yet few minerals are capable of serving as ores of this metal, because they do not contain it in the right combination or in sufficient quantity to make its extraction possible or profitable.

The iron ores having the greatest commercial value at the present day are usually those which are favorably located, of high quality, in considerable quantity, and possessing a structure such as to render their extraction easy. These four requirements have been met to such an eminent degree by the deposits located in the Lake Superior district that they now form the main source of supply for furnaces in the eastern and central states, and many of the iron mines in the eastern part of the United States have found it difficult to compete with them, although it is true that a number of deposits are worked to supply local demand, owing to their proximity to furnace, flux, and coal, or because they possess certain desirable characteristics.

Iron-ore Minerals. — The ore minerals of iron, together with their composition and theoretic percentage of metallic iron, are:—

MAGNETITE.	Magnetic iron ore, Fe_3O_4	72.4%
HEMATITE.	Specular iron ore, red hematite, fossil ore, Clinton ore, Fe_2O_3	70%
LIMONITE.[1]	Brown hematite, bog iron ore, ochre, brown ore $2Fe_2O_3, 3H_2O$	59.89%
SIDERITE.	Spathic ore, blackband, clay-iron stone, kidney ore, $FeCO_3$	48.27%

Of subordinate value:—

PYRITE.	FeS_2	46.6%
FANKLINITE.	$(Fe, Zn, Mn)O, (Fe, Mn)_2O_3$	± 44.1%
PYRRHOTITE.	Chiefly $Fe_{11}\ S_{12}$	± 61.6%

Magnetite is black, often granular, and may run high in titanium, especially in those occurrences found in basic igneous rocks. Hematite is red to brownish red, steel-gray, or even black. It is commonly fine-grained, but the specular varieties may be quite coarse. It ranges from massive to powdery, and has a specific gravity of 5.2. Limonite is never crystalline, and varies widely in appearance; some forms are powdery, others massive, and these may be porous, vesicular, stalactitic, or even, though rarely, solid. The specific gravity is 3.8. The color is brown to brownish yellow on the fracture, but may be black and shining on the natural surface. Göthite (Fe_2O_3, H_2O) and other hydrous oxides with less water than limonite are sometimes associated with it. Siderite, when occurring in commercial quantities, is rarely in cleavable form, but occurs as a fine-grained rock, with impurities. Hematite is by far the most valuable of the iron-ore minerals, chiefly on account of its easier reduction, but also because of the greater richness of the known important deposits.

---

[1] The group name "*brown ore*" is sometimes used to include several hydrous oxides, such as limonite, turgite, and göthite.

The deficiency in iron contents shown by many ores is due to the presence of common rock-forming minerals in the gangue, the impurities which they supply being alumina, lime, magnesia, silica, titanium, arsenic, copper, phosphorus, and sulphur. The effect of the last six is in general to weaken the iron.

Silica is objectionable because it displaces iron, and because just so much lime is required to flux it, but some furnaces turn out iron for foundry purposes containing 10 or more per cent. Ores carrying as high as 40 per cent SiO_2 are used in small quantities. Lime in small amounts does no harm, but in large quantities needs to be fluxed off. It is not present in any quantity in limonite, but may run high in the Clinton ores. Alumina may run somewhat high in limonites, because of admixed clay. Pyrite is the common source of the sulphur, but in some limonites it may come from gypsum or barite. Titanium, a common but injurious ingredient, is found in many magnetite deposits (see Titaniferous magnetites, also refs. 28, 30) and up to the present time has rendered them practically useless, not because it interferes with the quality of the iron, but because it makes the ore highly refractory, and drives much of the iron into the slag. Experiments have been taken looking towards the utilization of these titaniferous magnetites for the manufacture of ferrotitanium. Manganese, when present, is found mostly in the limonite ores, and for certain purposes is desirable. It is also prominent in some of the Lake Superior ores. Apatite yields the phosphorus. As this cannot be eliminated in either the blast furnace or the acid converter used in making Bessemer steel, and as the allowable limit of phosphorus in pig iron used for this purpose is $\frac{1}{10}$ per cent, a distinction is usually made between Bessemer and non-Bessemer ores, the maximum amount of phosphorus permissible in iron ore to be used for this purpose being $\frac{1}{1000}$ of the percentage of metallic iron contents of the ore. The phosphorus contents of many high-grade ores falls considerably below the allowable limit.

Classification. — The iron-ore deposits found in the United States have originated in a number of different ways, but the chief types may be grouped as follows: 1. Magmatic segregation deposits

(Lake Sanford, New York, etc.). 2. Contact-metamorphic deposits (Iron Springs, Utah; Hanover, New Mexico). 3. Sedimentary ores (Clinton hematite, bog ores, etc.). 4. Ores concentrated by meteoric waters, and deposited as replacements (some Lake Superior hematites, Oriskany limonites), or in residual materials (Virginia Cambro-Silurian limonites). 5. Lenticular masses in metamorphic rocks, of variable origin (some magnetite and pyrite deposits). 6. Gossan ores (limonite capping of many sulphide ore bodies).

Iron-ore bodies may show a variety of form, but many of the important deposits known in this country are lens- or basin-shaped in outline. Irregular masses and beds are not uncommon.

The iron ores found in the United States are widely distributed and their age ranges from pre-Cambrian to Recent. The occurrences of the different kinds of ore are best discussed separately, and for practical as well as other purposes a mineralogic and geographic grouping seems better than a genetic one.

MAGNETITE

Magnetite occurs in the United States (Fig. 123) (1) as lenticular masses commonly in metamorphic rocks; (2) as more or less lens-shaped and tabular bodies in igneous rocks; (3) as sands on the shores of lakes and seas; (4) as contact-metamorphic deposits;

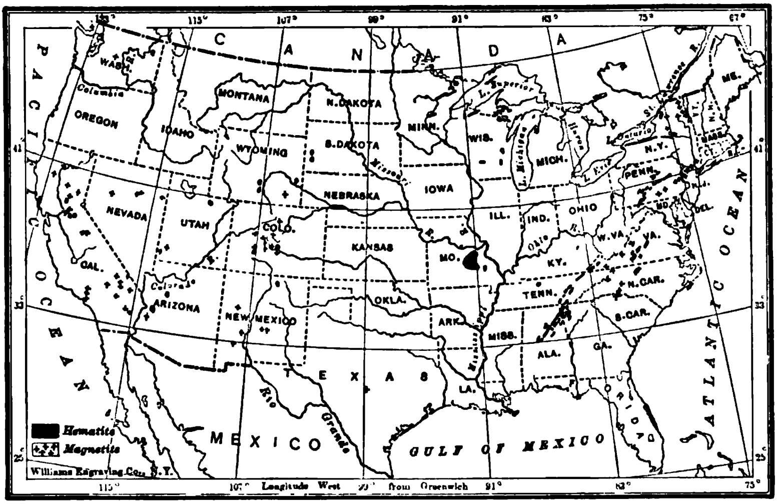


FIG. 123. — Map showing distribution of hematite and magnetite deposits in the United States. (*After Harder, U. S. Geol. Surv., Min. Res.*, 1907.)

(5) as replacements in limestone, not of contact-metamorphic character; (6) as veins, and (7) in residual clays.

The first class includes the most important deposits now worked in this country. The second and third groups run too high in titanium to have any commercial value at the present time, but the second may become of importance in the future, and moreover some of its representatives are of large size. Examples of the fourth class are known at a number of points in the West, and while few of them are worked, they may some day become of great importance. They carry hematite in addition to magnetite. The fifth, sixth, and seventh groups are unimportant.

Distribution of Magnetites in the United States (Fig. 123). *Non-Titaniferous Magnetites.* — These are usually found in the form of lenticular deposits in metamorphic rocks. The most important series of occurrences lies in the crystalline belt of rocks extending from New York into Alabama, deposits being known in New York, New Jersey, Pennsylvania, Virginia, and North Carolina.

The lenses, which are interbedded with gneisses of either acid or basic character and often conform with the latter in dip and strike, are of variable size, and may occur either singly or in series, the ore body commonly showing pinching and swelling, or even faulting. Well-defined boundaries are sometimes wanting. Feldspar, hornblende, and quartz are common gangue minerals, while apatite is prominent in some. Although the ore as mined is frequently of sufficient purity to be shipped direct to the blast furnace, in some instances it is so lean as to require concentration by magnetic methods. A description of one or two occurrences will serve as types:

Adirondack Region, New York (27, 30) — The rocks of the Adirondack region (Fig. 124) are almost exclusively of pre-Cambrian age, with occasional inliers of the bordering Paleozoic strata, whose basal member, the Potsdam sandstone, rests unconformably on the older crystallines. The latter have in most cases been subjected to powerful compression, and sometimes greatly changed by metamorphism, in fact so much so that their original character is determinable with difficulty.

The following members are recognized, beginning with the oldest:

I. *Metamorphic rocks.* — 1. *Sedimentary or Grenville Series.* These consist of limestones and dolomites, often impregnated with pyrite, graphite, and silicates, and by an increase in the latter may pass into schists. Both rock types occur in long narrow belts, bounded by sedimentary gneisses. 2. *Gneisses of acid to basic character,* often showing garnet, sillimanite, graphite, cyanite, pyrite, etc. 3. *Amphibolites*, composed mainly of hornblende or feldspar, and which may be metamorphosed dikes or magnesian shale. 4. *Quartzites* of infrequent occurrence. 5. *Gneisses* of doubtful relationships.

II. *Igneous rocks.* — These include: (1) anorthosite (the earliest), gabbro, syenite, and granite, all connected by intermediate rock types and probably representing derivations from the same magma. (2) Dikes, mostly diabases.

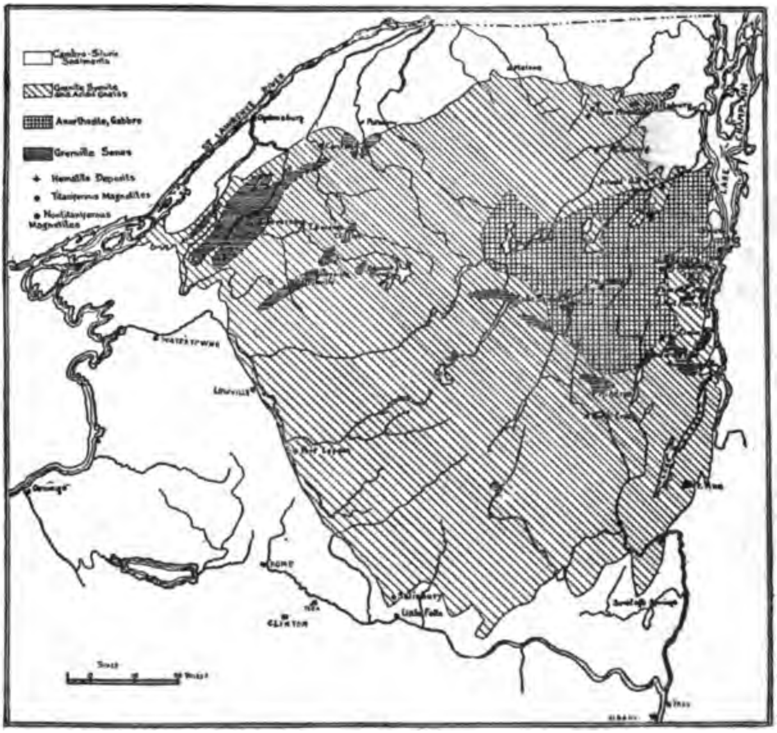


FIG. 124. — Geologic map of Adirondack Region, New York, showing location of iron-ore deposits. (*After Newland, Econ. Geol., II.*)

Ores. — The non-titaniferous magnetites are the most widespread of the Adirondack ores, and occur on both the eastern and western side of the mountains.

The ores vary from impure lean varieties, consisting of magnetite mixed with the country-rock minerals (*i.e.* quartz, feldspar, pyroxene, hornblende, etc.), to pure magnetite. The richest ore averages 60 to 70 per cent iron, and comes chiefly from Mineville, while those ores carrying under 50 per cent have to be concentrated. The phosphorus content is variable, but seems to be lower in the leaner ones, while in the non-Bessemer ores it may reach 2 per cent. The amount of sulphur is also changeable, but is highest in those ore bodies found in the Grenville gneiss.

While the ore bodies are variable in shape they show in general a somewhat lenticular cross section, with the tabulation extending parallel with the strike; but regularity is more common on the north and west sides of the province, for in the eastern districts there is the greatest irregularity due to a complexity of pinches, swells, and compressed folds. The wall rocks include gneisses of granitic, syenitic, and dioritic composition, as well as schists and occasionally limestones.

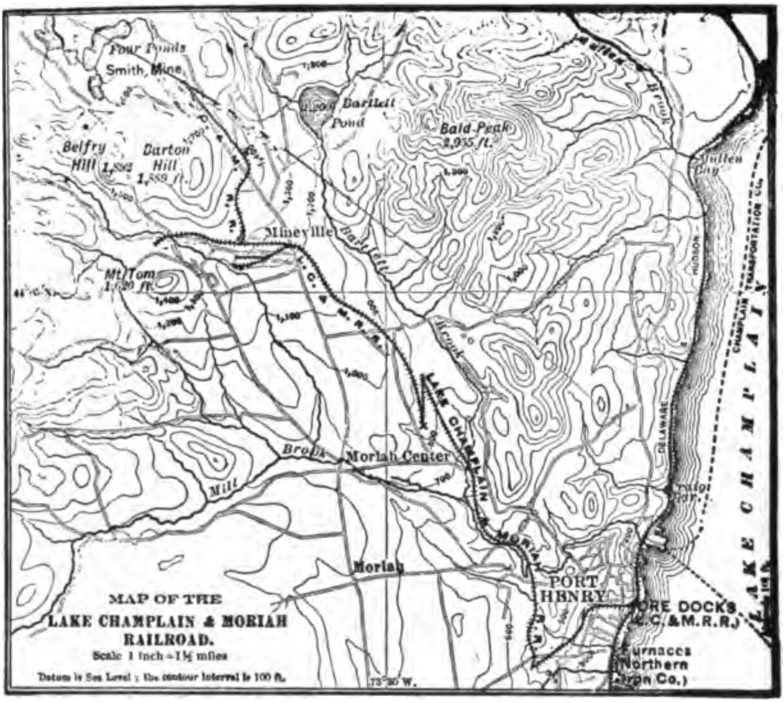


FIG. 125. — Map of Mineville, N. Y., iron-ore district. (*After Granbery, Eng. and Min. Jour., LXXXI.*)

Mineville, New York. — The ore bodies at this locality are the largest and most productive in New York State at the present time. They are of lenticular character, but in some cases the lenses are so

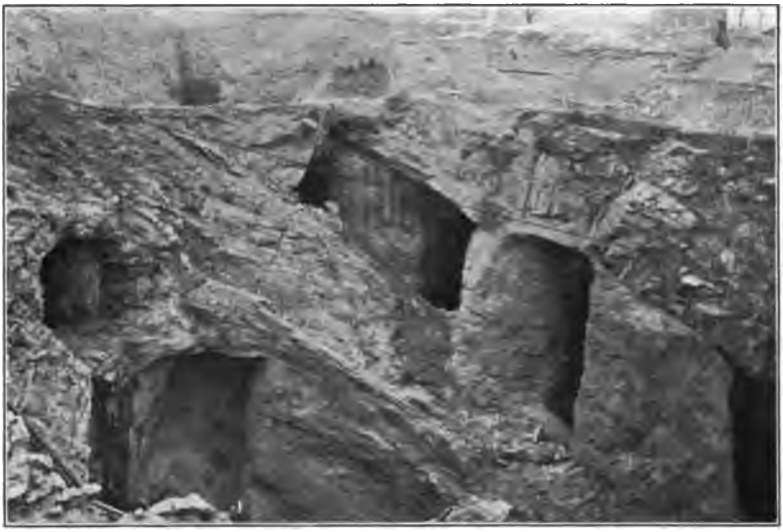


FIG. 1. — View of open cut in magnetite deposit, Mineville, N. Y. The pillars are left to support the gneiss hanging wall. (*After Witherbee, Iron Age, Dec. 17, 1903.*)

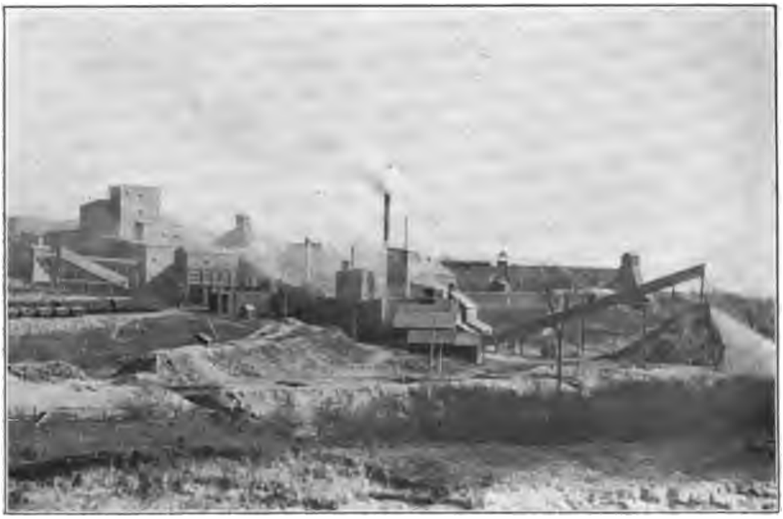


FIG. 2. — General view of magnetic separating plants and shaft houses, Mineville, N. Y. (*After Witherbee, Iron Age, 1903.*)

flat and of such extent as to be commonly spoken of as beds; moreover, some of them have been bent over into a southwesterly pitching fold, whose crest has been stretched and pinched, while faulting at the northern end of this has complicated the structure.

The ores occur as integral members of the syenite series, and are in the form of layers conformable to the banding or foliation of the inclosing rocks.

There are at least three large ore bodies (Fig. 126), viz.:—

1. The Barton Hill ore body, forming a practically continous bed, whose outcrop is approximately 3500 feet long in a direction a little east of north.

2. The Harmony bed, lying to the southwestward of Barton Hill, and striking northwest, with a rather flat southwest dip. It is 10 to 20 feet thick and cut by several narrow trap dikes which occupy fault planes of 10 to 50 feet displacement.

3. A large ore body which appears to be made up of three principal and separated parts, known as the Miller, the Old Bed or Mine 23, and the "21"-Bonanza-Joker. This is the chief source of the ore. There is some doubt whether there is any connection between the Joker and the Harmony. This Old Bed group extends in a practically unbroken stretch for about a half mile, exhibiting at the same time a most complex fold, referred to above.

The ores are granular masses of magnetite which in the Barton Hill group were prevailingly of Bessemer grade, but which in the Old Bed series are high in phosphorus.

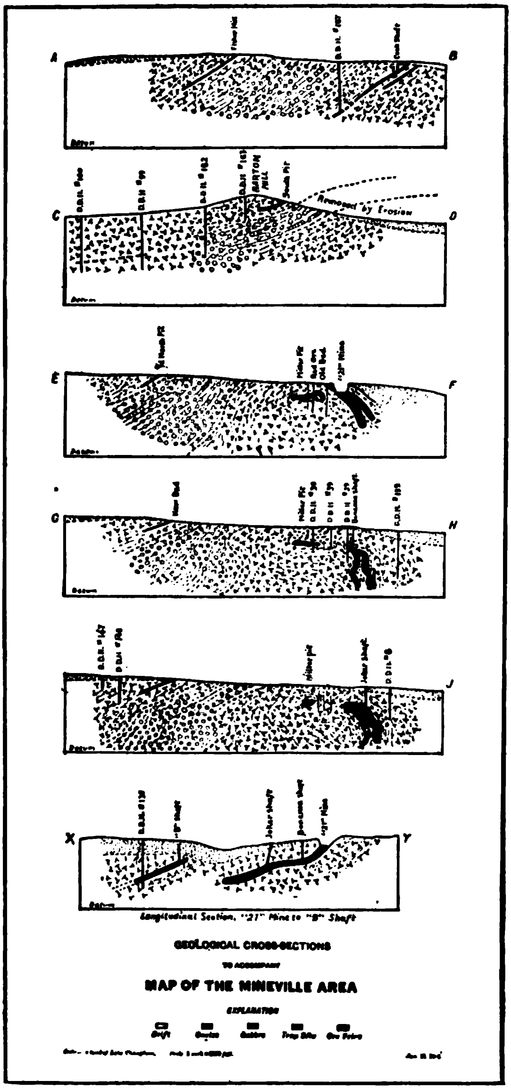
The lean ores are mixed with the minerals of the wall rocks, and among these the basic syenite is the chief one.

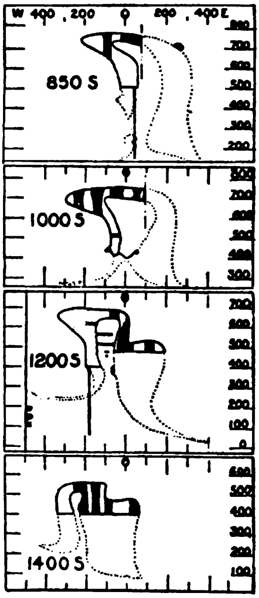
At Lyon Mountain (30) the ore is a lean magnetite traceable for 6 miles and from 20 to 200 feet wide, and occurs in a rock intermediate between granite and syenite. Most of the ore is low in phosphorus, the concentrates carrying about .008 per cent and 65 per cent Fe.

New Jersey. — In northern New Jersey, the magnetite deposits form layers or bands in the Franklin (pre-Cambrian) limestone, or as flat lenses in the associated gneisses.

The ore according to Bayley (24*a*) consists mainly of magnetite, hornblende, pyroxene, and apatite, sometimes intimately mixed. Pyrite and quartz are not uncommon, and all the associated minerals occur in the country gneiss.

The ore bodies, which are lens-shaped, lie with their longer axes conforming to the foliation of the gneisses, and the ore usually grades into the gneiss, although sharp boundaries are in some cases known. Several lenses may overlie each other, and then the intervening rock may be either gneiss, pegmatite full of magnetite, or coarse-grained hornblendic rock, with ore veinlets paralleling the foliation of the gneiss. This series of magnetites extends northeastward into the Highland region of New York.


A
B
C
D
Removed by Erosion
E
F
G
H
J
X
Y
Longitudinal Section, "21" Mine to "B" Shaft
GEOLOGICAL CROSS-SECTIONS
TO ACCOMPANY
MAP OF THE MINEVILLE AREA
EXPLANATION
Drift



FIGS. 9, 10, 11 AND 12, TYPICAL CROSS-SECTION.

FIG. 126. — Sections of the Old, "21"-Bonanza-Joker ore beds, Mineville, N.Y. (*After Granbery, Eng. and Min. Jour., LXXXI.*)

Origin of Magnetites. — The origin of the magnetites found in the gneisses has formed a most puzzling problem to geologists, whose correct solution depends in part at least on the correct interpretation of the origin of the inclosing rocks.

If the gneisses are of sedimentary origin, then it is possible that the ores may represent metamorphosed deposits of magnetite sands, limonites, or siderite, and the parallelism of the ore bodies with the foliation of the gneisses might be regarded by some as evidence in favor of such a view.

But even if the gneisses were of sedimentary origin, it might still be possible that the ores were of later introduction, as has been suggested by some. Thus Keith held the view that the North Carolina magnetites were replacement deposits (26), while Kemp formerly advanced the theory that the ore bodies at Mineville (27) have been formed by iron-bearing magmatic waters, which were given off from the neighboring gabbros and penetrated the gneisses while the latter were probably still at great depths, and before their metamorphism was complete. The presence of apatite and fluorite was thought to show that mineralizing vapors also played a part. A similar origin was suggested by Spencer for the New Jersey magnetites (34).

Recent studies by Kemp and Newland in the Adirondacks (30) seem, however, to indicate that the acid gneisses are probably of igneous origin, and that the magnetites themselves are products of magmatic differentiation. That there is no obstacle to this theory is shown by Newland, who points out that the acid igneous rocks of that region contain a large excess of iron over the amounts combined with the lime and magnesia to form silicates. The peculiar form of some of the ore bodies is likewise perhaps only explainable by this theory. A fact not to be overlooked, however, is the occurrence of fluorite, apatite, hornblende, etc., intercrystallized with magnetite, or the frequent association of the latter with pegmatite or vein quartz, a group of conditions which are suggestive of mineralizing agents, and their deposition by pneumatolytic or aqueous action.

Cornwall, Pennsylvania (35). — A somewhat unique deposit occurs at Cornwall, Lebanon County, Pennsylvania, and at several other localities in southern Pennsylvania. The ores are found along the contact of Triassic diabase, with Cambro-Ordovician limestones or more rarely Triassic shales, and consists mainly of magnetite, but carries sufficient pyrite to require roasting, and occasionally a little specular hematite. The ore forms large and small masses of irregular shape, lying either within the sediments or along the contact, and while it appears to be a true contact deposit, the contact silicates are not prominent. The ore averages about

45 per cent iron, is low in phosphorus, but high in sulphur, silica, lime, and magnesia. It also carries some copper.

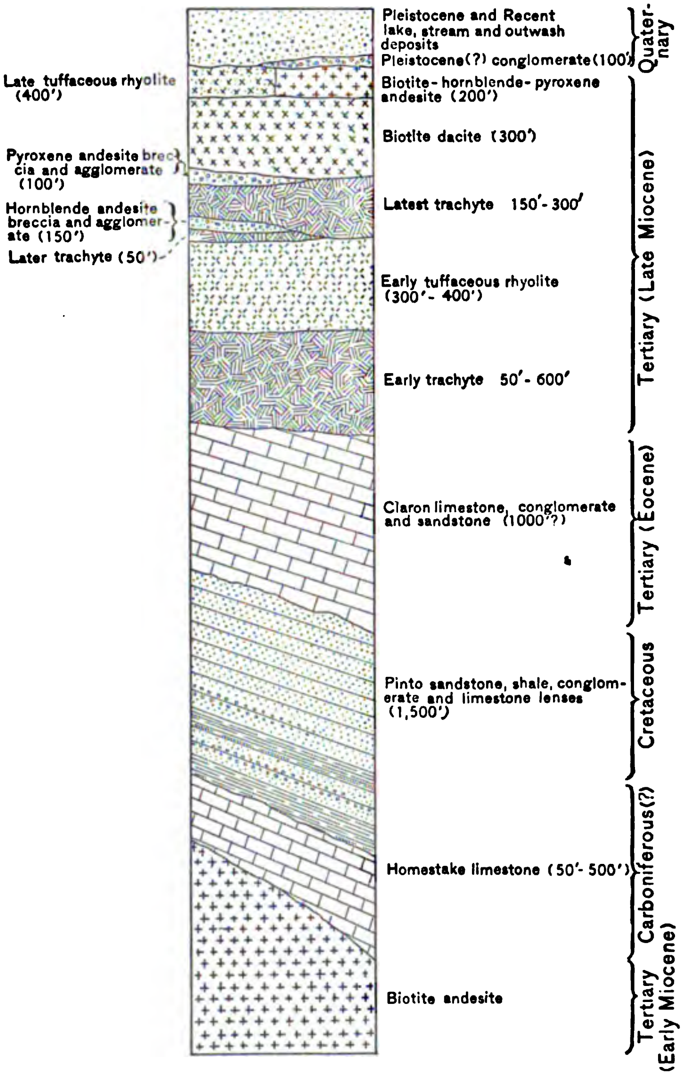

Pleistocene and Recent lake, stream and outwash deposits
Pleistocene(?) conglomerate (100')
Quaternary
Late tuffaceous rhyolite (400')
Biotite-hornblende-pyroxene andesite (200')
Biotite dacite (300')
Pyroxene andesite breccia and agglomerate (100')
Hornblende andesite breccia and agglomerate (150')
Latest trachyte 150'-300'
Later trachyte (50')
Early tuffaceous rhyolite (300'-400')
Early trachyte 50'-600'
Tertiary (Late Miocene)
Claron limestone, conglomerate and sandstone (1000'?)
Tertiary (Eocene)
Pinto sandstone, shale, conglomerate and limestone lenses (1,500')
Cretaceous
Homestake limestone (50'-500')
Carboniferous(?)
Biotite andesite
Tertiary (Early Miocene)

FIG. 127. — Geologic column of the Iron Springs, Utah district. (*After Leith and Harder, U. S. Geol. Surv., Bull.* 338.)

Other Occurrences (12). — Small deposits of magnetite are found in the limestones of the Shenandoah Group and their residual clays in southwestern Virginia (12, 22 *a*). The magnetite, which is associated with hematite and siderite, is of high grade and low in phosphorus (22 *a*). Magnetite occurs sparingly in the Marquette Range of Michigan, where it is found in the schists. Contact-metamorphic deposits are found at a number of localities in the West, but the chief occurrences are in Colorado, New Mexico, Utah, and California. Few of these have been described in detail.

Iron Springs, Utah (29). — Iron deposits are widely scattered over the western states, but few have been worked, owing to the limited demand in that region. They can be regarded, however, as reserves which may become of importance in the future. Among the best known of these are those of the Iron Springs district of southwestern Utah.

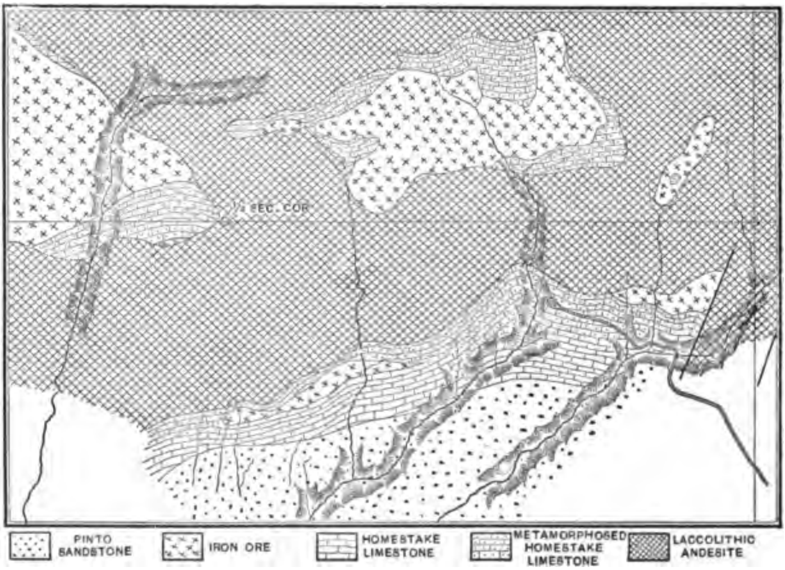


FIG. 128. — Map of a portion of the Iron Springs, Utah district, showing occurrence of iron ore in limestone near andesite contact, and also in the igneous rock. (*After Leith and Harder, U. S. Geol. Surv., Bull.* 338.)

At this locality the series of sedimentary rocks ranges from Carboniferous to Pleistocene (Fig. 127), and is intruded by three laccoliths of biotite andesite, which have especially affected the Homestake (Carboniferous) limestone, and to a lesser extent the Claron (Tertiary) limestone.

The ore bodies are of three types, viz.: (1) fissure veins in andesite; (2) fissure and replacement deposits on the contact of the andesite and Carboniferous limestone; and (3) as breccia cement in Cretaceous quartzite.

The second of these is the most important, and while the ore bodies are roughly lens-shaped, with their longer diameters parallel to the contact, still there are numerous irregularities, due to faulting and other causes. The vertical dimensions are unknown, as the deepest test shaft is down only 130 feet, and has not reached water level.

The ore consists of magnetite and hematite with a small amount of limonite, the first two, of course, being characteristic of contact-metamorphic deposits. The ore shows a hard, crystalline texture at the surface, but, as is sometimes found in arid regions, becomes softer with depth. The gangue is chiefly quartz or chalcedony near the surface, but calcite increases with depth. The contact minerals, garnet, diopside, apatite, mica, hornblende, and other silicates, are minor constituents.

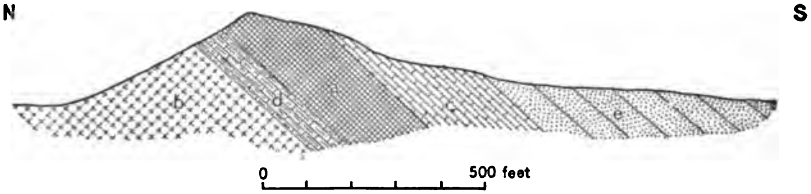


FIG. 129. — Cross section of Desert Mound contact deposit, Iron Springs, Utah district. *a*, iron ore ; *b*, laccolithic andesite ; *c*, Homestake limestone ; *d*, altered Homestake limestone ; *e*, Pinto sandstone. (*After Leith and Harder, U. S. Geol. Surv., Bull.* 338.)

While much of the ore runs above 60 per cent in iron, the average is about 56. Phosphorus is uniformly high, but sulphur, copper, and titanium are not in prohibitive amounts.

Leith and Harder believe that the ores are closely related in origin to the andesite laccolite intrusions, and suggest the following:

The contact metamorphism first produced a zone of about 60 feet width, containing varying amounts of albite, kaolinite, actinolite, diopside, quartz, orthoclase, serpentine, phlogopite, andradite, iron ores, osteolite (earthy apatite), andalusite, wollastonite, calcite, etc. There is also glassy material which appears to represent fused wall rock. Solutions given off by the andesite dissolved out the lime and magnesia carbonates, while the residue recrystallized to form silicates. Later the iron was brought in from the eruptive, probably as ferrous chloride, which reacted with water (above 500° C.), yielding magnetite and hydrochloric acid, thus:— $3\ FeCl_2 + 4\ H_2O = Fe_3O_4 + 6\ HCl + H_2 + 77$ calories.

The HCl attacked the limestone, which was replaced by the magnetite.

This view that the eruptive contributed but little material to the contact zone is disputed by Kemp, who, by taking the author's analyses and recasting them, shows that the reverse may be true. Moreover, if Leith's conclusions are true, then a contact zone 60 feet thick must represent a shrunken residue of a limestone belt 300 feet thick which, as pointed out by Kemp, seems hardly possible.

Analyses of Magnetites. — The following table gives the composition of non-titaniferous magnetites from a number of localities. It is not possible in all cases to obtain analyses of recent date.

ANALYSES OF MAGNETITES

	I	II	III	IV	V	VI	VII	VIII	IX
Fe . .	60.03	60.91	61.69	59.93	56.05	64.9	56.00	61.85	89.4[1] 7.5[2]
SiO_2 .	4.48	4.49	18.90	7.72	7.76	3.98	7.	4.74	2.4
P . .	1.635	1.548	1.30[5]	.08	.036	.021	.2	.112	.011
S . .	.021	.027	1.23	.19	.06	.071	.057	.015	.099
Ti . .	.12	.03	1.30	—	—	—	—	—	—
Cu . .	—	.007	—	—	—	.005	.027	—	—
Moist .	.28	.25	—	—	—	—	3.	2.62	—
Mn .	—	—	.55[4]	.17	none	.158	.196	2.42[3]	.18[4]
Al_2O_3 .	—	—	12.48	—	—	.324	1.	.74	—
CaO .	—	—	4.45	—	—	1.010	4.	.16	—
MgO .	—	—	.86	—	—	1.131		.95	.3

I. Sample 60 carloads. II. Sample 35 carloads, 21 pit, both Mineville, N. Y., N. Y. State Museum, Bull. 119 : 82. III. Warren County, N. J., N. J. Geol. Surv., Ann. Rept. 1873 : 80. IV. Philpot, Patrick County, Va.. U. S. Geol. Surv., Bull. 380 : 219. V. Limestone magnetite. Abingdon, Va., *Ibid.* VI. Cornwall, Pa., Amer. Inst. Min. Engrs., Trans. XIV : 892. VII. Iron Springs, Utah, U. S. Geol. Surv., Bull. 338. VIII. Hanover, N. Mexico, U. S. Geol. Surv., Bull. 380 : 212. IX. Shasta County Calif., Econ. Geol., III : 472.

Titaniferous Magnetites (24, 28, 30). — These form a peculiar class by themselves, and with only one or two exceptions are found always associated with rocks of the gabbro family. The ore bodies occur in the midst of igneous intrusions, and according to Kemp seem to have been formed by the segregation of fairly pure titaniferous iron oxide, either before or during the process of cooling and consolidation.

Mineralogically they may contain both ilmenite, FeO, TiO_2 (FeO, 46.75 ; TiO_2, 53.25), and titaniferous magnetite, which is of variable composition. The gangue minerals may be pyroxene, brown hornblende, hypersthene, enstatite, olivine, spinel, garnet, and plagioclase. The ores are usually low in phosphorus and sulphur, but Va, Cr, Ni, and Co are almost always present. In the United States they are found in New York, New Jersey, Colorado, Minnesota, Wyoming, Virginia, and several other states, but are not worked.

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[1] Fe_3O_4. [2] Fe_2O_3. [3] MnO_2. [4] MnO. [5] P_2O_5.

The following analyses illustrate their composition: —

ANALYSES OF TITANIFEROUS MAGNETITES

	1	2	3	4	5	6	7	8
FeO .	70.50	80.78	27.95	79.78	70.80	28.84	24.55	51.44[2]
Fe_2O_3 .	—		15.85			14.05	48.97	—
TiO_2 .	14.00	12.09	15.66	12.08	19.52	10.11	23.18	16.76
SiO_2 .	8.60	2.02	17.90	.75	1.39	22.35	2.15	—
Al_2O_3 .	4.00	2.58	10.23	4.62	4.00	5.26	—	—
Cr_2O_3 .	—	2.40	.51	.32	—	Tr.	—	—
V_2O_5 .	—	—	.55	Tr.	—	.18	—	—
MnO .	—	—	Tr.	.28	—	.43	—	—
CaO .	1.60	—	2.86	.13	—	1.17	—	—
MgO .	2.30	—	6.04	2.04		16.10	—	—
H_2O .	—	—	.04	—	—	.42	—	—
P_2O_5 .	—	.03	.14	—	.022[1]	.02	—	.97[1]
S .	—	—	—	—	.028	.38	.03	—
Na_2O .	—	—	—	—	—	.44	—	—
K_2O .	—	—	—	—	—	.10	—	—
Zn .	—	—	—	—	—	.71	—	—
Cu .	—	—	—	—	—	.08	—	—
Co, Ni.	—	—	—	—	—	7.08	—	—
Pb .	—	—	—	—	—	— Tr.		—

1. Grape Creek, Col. 2. Mayhew Range, Minn. 3. Split Rock, N. Y. 4. Greensboro, N. Ca.; Nos. 1–4, U. S. Geol. Surv., 19th Ann. Rept., III : 377, 1899. 5. Lake Sanford, N. Y., N. Y. State Mus., Bull. 119 : 163. 6. Cumberland Hill, R. I., Amer. Jour. Sci., Jan., 1908. 7. Iron Mountain, Wyo., U. S. Geol. Surv., Bull. 315 : 209. 8. Marksville, Va., Min. Res. Va., 1907 : 419.

Descriptions of two localities will serve to illustrate the mode of occurrence of these titaniferous ores.

New York (28, 30). — Titaniferous magnetite deposits of large size occur in the Adirondack region, and while they carry TiO_2 as an essential ingredient, the percentage of this element may vary considerably. Thus in the Adirondack ores it is at least 8 to 9 per cent (TiO_2), and averages 15 per cent.

The ores are closely associated with gabbro-anorthosite intrusions, and are found chiefly in Essex and southern Franklin counties. At Lake Sanford, where the most important ore bodies occur, the small deposits are found in gabbro dikes cutting the anorthosite and having a tabular form conformable with the strike of the dikes, but large ones occur in the anorthosite and may be segregations during cooling, or actual intrusions forced into the anorthosite after partial consolidation.

---

[1] P. [2] Fe.

The ores are essentially magnetite and ilmenite, the richest showing little else and running about 60 per cent Fe. The magnetite grains are recognizable by parting planes parallel to the octahedron and smooth breaks, while the ilmenite grains show a rough fracture, brighter luster, and but slight magnetism.

Other minerals present are plagioclase, pyroxene, hornblende, biotite, olivine, garnet, pyrite, apatite, spinel, and quartz. The usual order of crystallization is reversed, being silicates, pyrite, ilmenite, magnetite. Analyses of the Sanford deposits show 70.73–87.60 Fe_3O_4, .87–2.46 SiO_2; 9.45–20.03 TiO_2; .53–4.00 Al_2O_3; .007–.022 P; .027–.028 S.

The following results were obtained by magnetic separation after crushing to 40 mesh. Finer crushing would probably improve the product.

	1	2	3
	MAGNETITE	CONCENTRATE	ILMENITE AND OTHER MINERALS
Fe_2O_3	55.9	54.39.	14.28
FeO	27.5	28.66	30.93
TiO_2	14.0	8.93	45.23

Wyoming (24). — An occurrence of titaniferous magnetite of some importance is found at Iron Mountain in southeastern Wyoming. Iron Mountain is a ridge 300 to 600 feet wide, and 1¼ miles long, which rises sharply from the anorthosite hills to the east and pre-Cambrian uplands to the west. The pre-Cambrian complex near the iron ore dike consists of three granular igneous rocks, viz. anorthosite, iron ore, and granite, the anorthosite, or oldest, being cut by dikes and lenticular masses of iron ore and granite.

The ore, which forms a dike 1¼ miles long, 40 to 300 feet wide, and has a northerly strike, is sharply bounded on both sides by anorthosite, and paralleled by several smaller dikes. It is a black, granular, holocrystalline rock, which carries as impurities biotite, olivine, and feldspar. The iron content averages about 50 per cent.

It is suggested (Ball) that the ore and anorthosite are differentiation products from a common magma, the iron having been intruded after the complete solidification of the anorthosite; but the relationship of the two is shown by the presence in each of similar minerals, although their proportions are different.

The granite is probably the youngest of the pre-Cambrian rocks, and grades into, as well as being cut by, a biotite-pegmatite which carries some magnetite.

Magnetite Sands. — These are found in those regions where the beach sands are composed of weathering products of metamorphic and igneous rocks. The sorting action of the waves serves to carry the heavy mineral grains high up on the beaches, where they form black streaks, composed mostly of magnetite (usually titaniferous), mixed with monazite, apatite, and other heavy minerals.

Deposits are known in this country on the shores of Lake Champlain, Long Island, etc., but they are of small extent as well as lacking in quality.

New Zealand and Brazil are said to possess magnetite sands of commercial value.

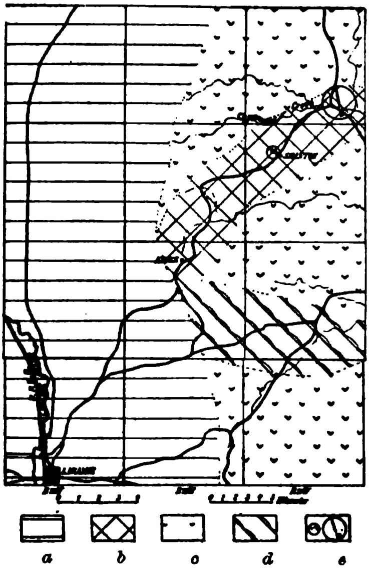

FIG. 130. — Map of Iron Mountain, Wyo., titaniferous magnetite deposit. *a*, post-Devonian; *b*, anorthosite; *c*, granite; *d*, gneiss; *e*, ore. (*After Kemp, Zeitschr. prak. Geol.*, 1905.)

HEMATITE

This is by far the most important ore of iron in the United States, having in 1908 formed about 88 per cent of the total production, and about 85 per cent of the hematite mined came from the Lake Superior region. The varieties mined in the United States include the earthy, specular, oölitic, and fossiliferous.

The deposits are mostly of basin-shaped character, having been formed largely by replacement, but contact deposits, bedded deposits, and other types are known.

Distribution of Hematite Ores in the United States (Fig. 123). — At the present day there are but two very important hematite-producing regions, in the United States, viz. the Lake Superior region and the Birmingham, Alabama, area. Other areas which are worked will also be referred to, but they are less important.

Lake Superior Region (45, 47). — Under this head are included a great series of deposits lying in the region surrounding the south and west sides of Lake Superior (13). The rocks are of remote geologic age, as can be seen from the following generalized section:—

Algonkian	Keweenawan Upper Huronian (iron-bearing) Middle Huronian (iron-bearing) Lower Huronian	Carries iron formation in	Mesabi Penokee Vermilion[1] Marquette Crystal Falls Menominee Cuyuna
Archæan	Laurentian (intrusive in Keewatin)		Marquette Vermilion
	Keewatin (iron-bearing)		Vermilion

Each of the above series is separated from its neighbor by a great unconformity due to intervals of elevation above the sea level and periods of erosion.

The ore-bearing districts themselves have been studied in considerable detail, but the intervening parts are less well known, and it is therefore difficult to correlate the major geological units of the several districts.

Character of formations. — The Archæan includes a complex series of acid and basic igneous rocks, and two or more sedimentary formations, including the iron formations and slate of the Keewatin. The Algonkian includes four unconformable sedimentary series, all associated with igneous rocks, the entire succession being separated by an unconformity from the Archæan below and the Potsdam above.

The iron ores occur as concentrations in the so-called iron formations, which range in thickness from a few hundred to a thousand feet.

In their present form these iron formations represent alterations of chemically deposited sediments, such as cherty iron carbonates, which are usually interbedded with normal clastic sediments such as slate and quartzite.

In general terms the iron formations may be described as consisting mainly of chert or quartz and ferric oxides, usually segregated into bands, but sometimes irregularly mixed. Jasper is a banded rock of highly crystalline character with the quartz layers colored red. Ferruginous chert differs from it in being less crystalline, and with the quartz either banded or irregularly mingled. This latter type is known as *taconite* in

---

[1] Not productive.

the Mesabi district. Other phases of the iron formation are clay slates, paint rocks (alterations of preceding), amphibole-magnetite schists, cherty iron carbonate, hydrous ferrous silicate (greenalite), and iron ores.

The original iron rocks were cherty iron carbonate, ferrous silicate, and pyritic iron carbonate, and unaltered remnants of these are still found.

Since their formation the rocks have been folded, faulted, and sometimes brecciated, and much of the ore is found in these structural troughs; but in some instances, as in the Mesabi Range, the ore bodies are somewhat flat as compared with their length and breadth.

The ores of the Lake Superior region vary from hard blue ores to soft earthy ones. They are mostly hematite with small quantities of limonite, but some magnetite is known in the Marquette district.

The following table, taken from Birkenbine's report gives a number of typical analyses. Many additional ones can be found in the reports on Mineral Resources issued annually by the United States Geological Survey.

TYPICAL ANALYSES OF LAKE SUPERIOR IRON ORES

CONTENT	MARQUETTE RANGE	MENOMINEE RANGE	GOGEBIC RANGE	VERMILION RANGE	MESABI RANGE
Iron	56.5	55.2423	56.308	61.36	56.0996
Phosphorus	.0353	.0594	.0338	.0373	.0365
Silica	4.584	6.7693	3.3961	4.2545	3.4867
Sulphur	.0089	—	—	—	—
Moisture	11.85	6.525	10.828	4.5649	12.3158

ANALYSES OF SILICEOUS ORES

CONTENT	MARQUETTE RANGE	MENOMINEE RANGE	VERMILION RANGE
Iron	42.27	42.129	51.1938
Phosphorus	.0316	.0244	.0498
Silica	35.834	34.141	22.3642
Sulphur	.0099	—	—
Moisture	1.23	2.2	3.21

Seven districts, or ranges, are recognizable in the Lake Superior region, viz. Marquette (48) and Crystal Falls (41) in Michigan;

Menominee (39) in Wisconsin; Penokee-Gogebic (42) on the Michigan-Wisconsin boundary; Mesabi (44), Vermilion (40), and Cuyuna (46) in Minnesota.

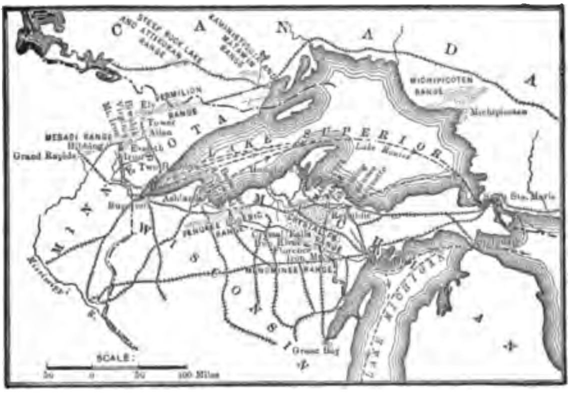

FIG. 131. — Map of Lake Superior iron regions (except Cuyuna), shipping ports, and transportation lines. (*After Grant, Min. Mag., X.*)

The general mode of occurrence of the ore in several of these is shown in Figs. 132 to 134, and they are referred to individually below.

Marquette Range (48). — This occupies a rather large area west and southwest of Marquette, Michigan, and carries iron formations in both the Upper and Middle Huronian, the latter being the more important. That of the Upper Huronian is underlain by quartzite and covered by slate, while the Middle Huronian iron formation is underlain by slate which in turn rests on quartzites. Igneous intrusions of Keweenawan age are common. The structure of the range is that of a great east-west synclinal basin containing a number of minor

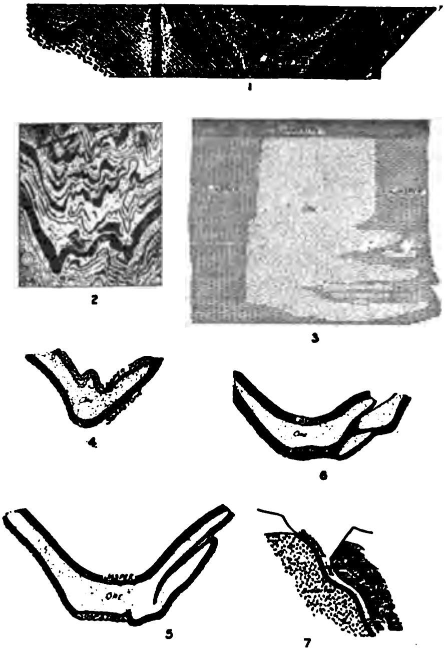

FIG. 132. — Sections of iron-ore deposits in Marquette range. (*After Van Hise.*)

folds, and while the ores occur on both limbs of the basin, they are most abundant on the northern one.

The ores may be divided into three classes, namely, (1) ores at the base of the iron-bearing Negaunee (Middle Huronian) formation, (2) the ores within the Negaunee formation, (3) detrital ores at the base of the Goodrich (Upper Huronian) quartzite. Ores of the first and second class are mostly soft hydrated hematite, while those of the third class are hard specular ores with some magnetite from metamorphism due to greater movements along the contact of the Middle and Upper Huronian during the faulting within these rocks themselves.

Menominee Range (39). — While this carries iron formations in both the Middle and Upper Huronian, only the former are commercially important and are confined to the southern part of the district. The iron ores are mainly gray, finely banded hematite with lesser amounts of a flinty hematite which shows local banding.

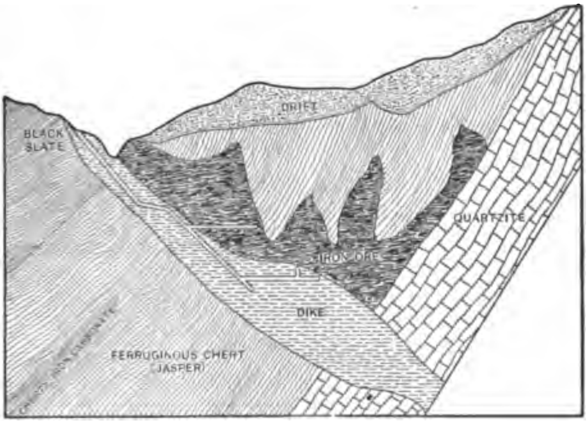

FIG. 133. — Generalized vertical section through Penokee-Gogebic ore deposit and adjacent rocks; Colby mine, Bessemer, Mich. (*After Leith.*)

Penokee-Gogebic Range (42). — The ores occur in Upper Huronian, the iron formation being overlain by slate and underlain by quartzite and black slate. The latter is covered by a gabbro of Keweenawan age, which is found in contact with the iron formation in places and has altered it to jasper and amphibole-magnetite rock. Most of the iron formation, however, is ferruginous chert. The steeply dipping sedimentary rocks are cut by dikes of basic igneous rocks, thus forming troughs in which the ores are concentrated. Most of the deposits reached depths of 1000 feet and upwards, but the horizontal extent is small. While soft hydrated hematite is the normal type of ore, still the hard slaty ore is not uncommon. Manganese is found in a few deposits.

Mesabi Range (44). — The rocks of this region are less folded and metamorphosed, and dip slightly to the southeast. The iron formation, which is mainly ferruginous chert, is overlain by a thick slate and under-

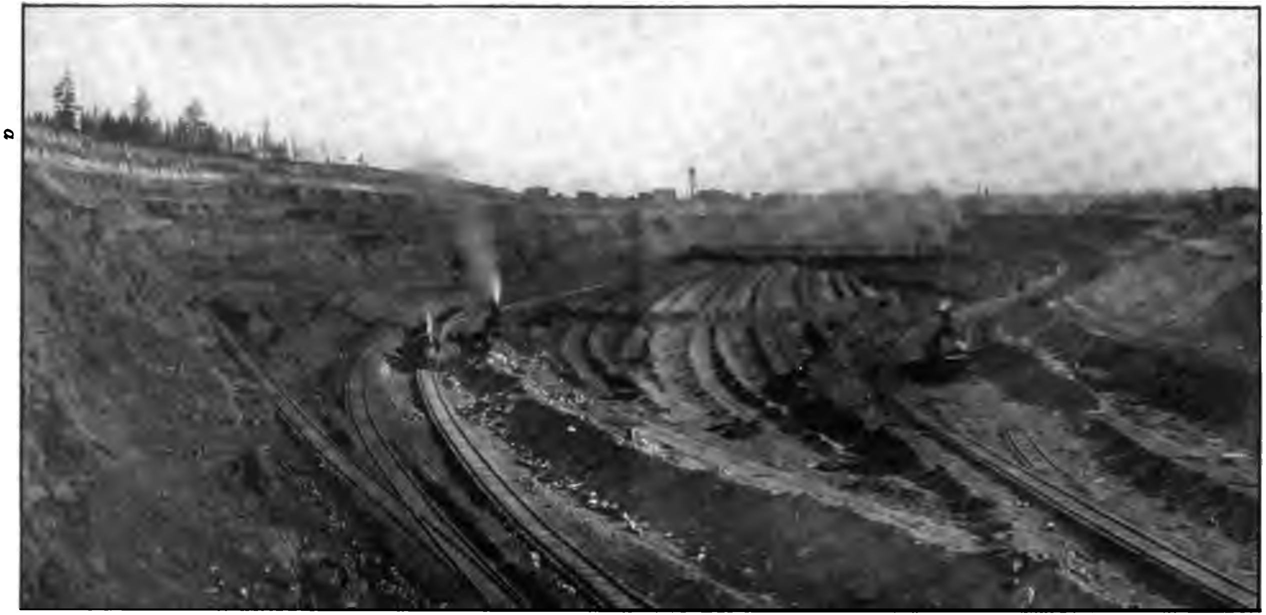

Plate XXXII. — General view of Mountain Iron mine, Mesabi Range, Minn., shows mining of ore with steam shovels, and covering of (*a*) glacial drift. (*Crandall and Maher, photo.*)

lain by a thin quartzite, which in turn rests on granite, or graywacke and slate of lower Middle Huronian. At the eastern end of the range the iron formation has been metamorphosed to amphibole-magnetite rock by a gabbro intrusion. The iron-ore deposits are very irregular in shape, but their horizontal extent is great as compared with their depth (Fig. 134), most of them being less than 200 feet. The mining is done mainly by open pits (Pl. XXXII), and the ore is a rather soft hematite of high grade. It preserves the stratification of the original iron formation and in places is found grading into the latter.

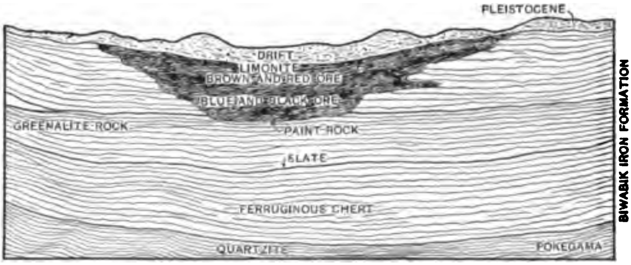

FIG. 134. — Generalized vertical section through Mesabi ore deposit and adjacent rocks. (*After Leith.*)

Vermilion Range (40). — The chief ore deposits occur in the highly folded and metamorphosed Keewatin rocks, and the iron formation is largely altered to jasper. The country rock is mostly greenstones in which the jasper occurs in basins or troughs. The ores associated with the jasper in these troughs usually have a greenstone foot wall and consist of dense hard red or blue hematite, which is sometimes brecciated but rarely specular.

Cuyuna Range (46). — This range lies to the southwest of the Mesabi range and shows a series of small northeast-southwest anticlines in a broad synclinal basin on whose northern limb the Mesabi range is situated, while on the southern limb we find the Penokee. Owing to the limited number of outcrops and lack of development at the present time, the geology is not yet perfectly known, but the formations seem to include quartzite and its altered equivalents, iron formations, slate, and intrusive granite and diorite. The ores form the altered and concentrated upper parts of the steeply dipping iron-formation strata, which are exposed by the erosion of the anticlines. The hanging wall is commonly chloritic slate and iron carbonate in varying proportions and degrees of alterations, while the foot wall is either a quartz schist or amphibole-magnetite schist. The ore bodies thus far found seem to be in the form of lenses 100 to 250 feet thick, with their longer dimensions parallel to the highly tilted bedding of the series.

Origin. — The origin of these ores has for years been a puzzling problem to geologists. Foster and Whitney considered them eruptive, while Brooks and Pumpelly looked upon them as altered limonite beds.

The work of Van Hise and Leith has shown us that the Lake Superior ores were concentrated in certain sedimentary iron formations, and it was at first believed that these sediments were derived from the weathering of land areas containing much igneous rock.

Further study has led them to conclude, however, that the iron formations have not only been derived in this way, but that the iron has actually been contributed by greenstone magmas directly to the water in magmatic solutions and that there are all intermediate stages between the two processes.[1]

The iron ore as first deposited consisted essentially of chemically precipitated iron carbonate or ferrous silicate (greenalite) with some ferric oxide, all finely interlayered with chert.

Later on, when these sediments were uplifted to form the land surface and exposed to weathering, the ferrous compounds, the siderite and greenalite, were oxidized to hematite and limonite. While this occurred mainly in place, some of the iron was carried off and redeposited elsewhere. This resulted in a ferruginous chert carrying less than 30 per cent of iron.

Further concentration of the iron to 50 per cent or over was accomcomplished mainly by the silica being leached from the bands of ferruginous chert.

Where the concentration of the ore has occurred in troughs, the chemistry of the process is thought to be as follows:—

> Part of the ferric oxide was deposited as an original sediment containing silica and other impurities, or in some cases as sulphides or carbonates. This was later enriched by the addition of iron carbonate. These were originally contained in the rocks near the surface, and became oxidized by percolating waters, which took up the carbon dioxide liberated, and were thus able to dissolve iron carbonates or silicates, which they came in contact with in their downward course toward the troughs in which the ore is found.
>
> The precipitation of the ore was then caused by these solutions meeting with others which had filtered in by a more open and direct path from the surface, and hence contained some free oxygen, which converted the dissolved iron compounds into oxides.
>
> The same solutions, carrying carbon dioxide, dissolved the alkalies out of the basic igneous rocks, and these waters were then able to dissolve silica. In some cases the solution of silica proceeded faster than the deposition of the iron ore, and made the rock quite porous. The general result was therefore a concentration of the iron and removal of silica.

The weathering processes have yielded mainly soft ores and ferruginous cherts, while metamorphism has formed hard red and blue

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[1] Can. Min. Inst., XI: 91, 1908.

PLATE XXXIII

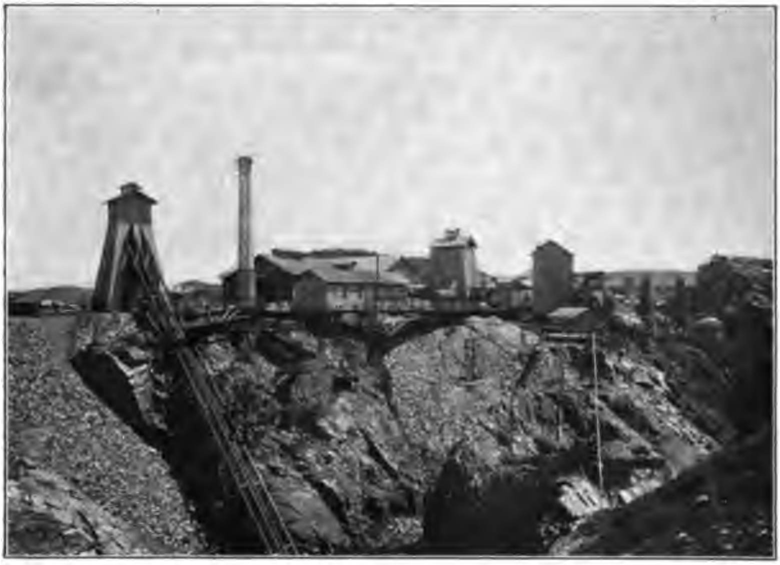

FIG. 1.—Iron mine, Soudan, Minn. Shows old open pit with jasper horse in middle.

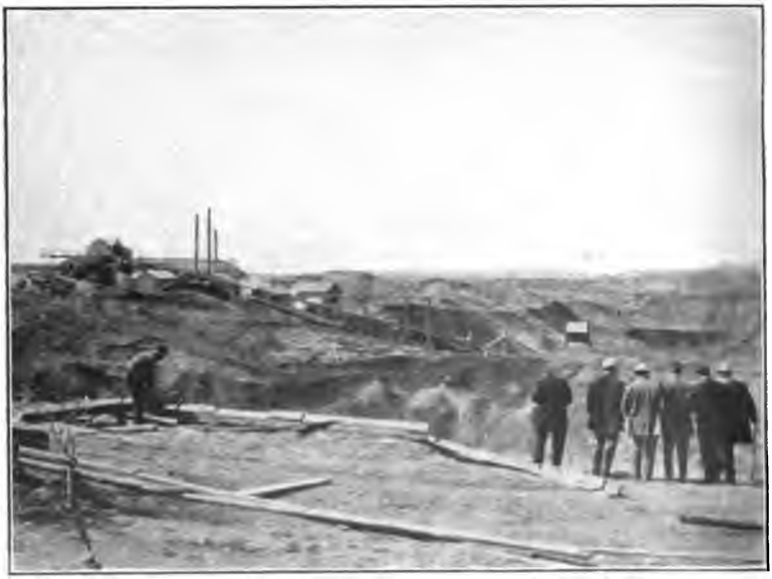

FIG. 2.—View of limonite pit near Ironton, Pa. (*H. Ries, photo.*)

specular ores and brilliant jaspers, as well as changed the iron formation into amphibole-magnetite schists.

Most of the rich ores are found above the 1000-foot level, except in the Mesabi district, where the deposits are shallow, as compared with their horizontal extent, some, however, being over 400 feet deep.

In the early period of mining many of the Lake Superior bodies were worked as open cuts, but with depth underground working has been resorted to. There are many deposits in the Mesabi district which are worked as open pits from which the granular ore is dug with a steam shovel and loaded directly on to the ore cars, which are run along the working face (Pl. XXXII).

The market value of the ores is based on the iron contents, percentage of water, and amount of phosphorus, and at times the manganese contents is taken into consideration. Some objection was at first raised to the fine character of the Mesabi ore and its tendency to clog the blast furnace, therefore requiring the admixture of lump ore from the other ranges; but this objection has disappeared, and some furnaces now use over 75 per cent of Mesabi ore in their charge.

The Lake Superior iron ore region is not only the most important in the world, but the production of some of the individual mines is startling. (See production of individual mines at end of this chapter.) The Marquette range was developed as early as 1849, the Mesabi as late as 1892, and the Cuyuna some years after this. The total yield of the Lake Superior region from 1850 to the end of 1908 has been about 434,000,000 long tons. While the output has been phenomenal, and the supply large, high-grade ore is no longer abundant, and much ore running high in silica is now shipped.

Wyoming (60). — Important deposits of hematite are found in the pre-Cambrian schists at several localities in Wyoming, viz. in the Hartville District, Laramie County, and near Rawlins, in Carbon County.

The Hartville deposits form a portion of the Hartville uplift, which is a broad, low dome similar to that formed by the Black Hills, and while the iron range extends from Guernsey to Frederick, a distance of 8 miles, the productive area extends only from a point 2 miles northeast and 1 mile southeast of Sunrise.

The pre-Cambrian sediments have been folded into a complex synclinorium, and faulting has been a common phenomenon, while the brecciation which accompanied both the folding and faulting was an important structural factor in the ore formation.

The most important ore bodies are lenses occurring in the schist along a limestone footwall, the ore either replacing the schist or to a lesser extent filling the joint, fault, and breccia cavities. These lenses range up to 1000 feet in length, and conform to the foliation of the schists. Detrital ores derived from the foregoing are also found.

The following geological section is involved:—

Pleistocene	Terrace gravels, alluvium, and wash.
Tertiary (Arikaree)	Sandstone.
Jura-Trias and Cretaceous	
Carboniferous nearly flat	Hartville 650′ thick. White or gray limestone. Red sandstone. Unconformity. Guernsey 150′ thick. Conglomeratic quartzite or sandy limestone.
Pre-Cambrian rocks, the stratified ones with steep dip.	Quartzose beds, partly conglomerate and associated jaspers. Unconformity. Interbedded siliceous limestones and muscovite and biotite schists with beds and lenses of quartz and jasper rock. Intrusives, diabase, aplites and pegmatites, biotite granite, gabbros, diorites, and porphyrites, derivative hornblende and chlorite schists.

The ores are high-grade hematites (chiefly hydrated), averaging over 60 per cent iron. Sulphur is absent, silica may be high, and much of the ore is non-Bessemer. Two grades of ore are recognized, viz. a hard gray hematite, and a soft greasy one of brown-red color.

Siderite and limonite are of subordinate importance, while the associated minerals are calcite, quartz, gypsum, chalcedony, barite, chrysocolla, etc. The copper minerals occur in the fractures in the hematite. Both types of hematite grade into the schist, but much of the soft ore has been derived from the hard by percolating waters.

Ball assigns an epigenetic origin to the ore, believing that it was deposited by descending water, because (1) the ore is along zones of maximum downward circulation, (2) lenses and veins are found along joints at a distance from the main body, and (3) the associated minerals, quartz, calcite, and limonite, are all water-formed ones. The magnetite and iron pyrite of the schist lying above the limestone footwall are regarded as the source of the iron. During pre-Cambrian times there was extensive erosion of this schist, and a downward transferal of this iron by carbonated surface waters flowing along the impervious limestone footwall, where it was precipitated by oxygen-bearing waters coming by a more direct path.

Clinton Ore (51–59). — This ore, which is also called fossil, pea, or dyestone ore, was given the first name on account of the ore bed

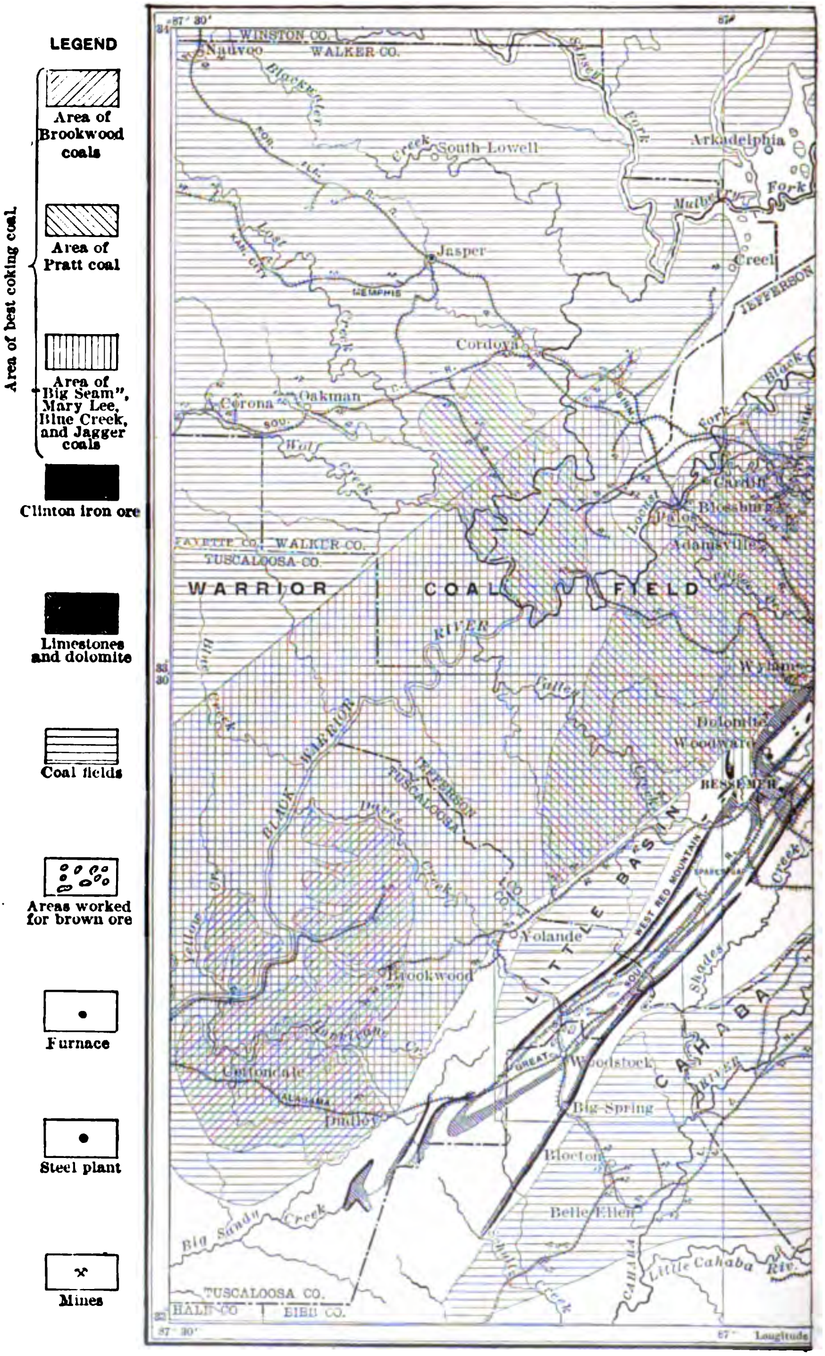

PLATE XXXIV. — Geologic map of western half of Birmingham, Ala., district. (*After Burchard, Amer. Inst. Min. Engrs., Bull.* 24, 1908.)

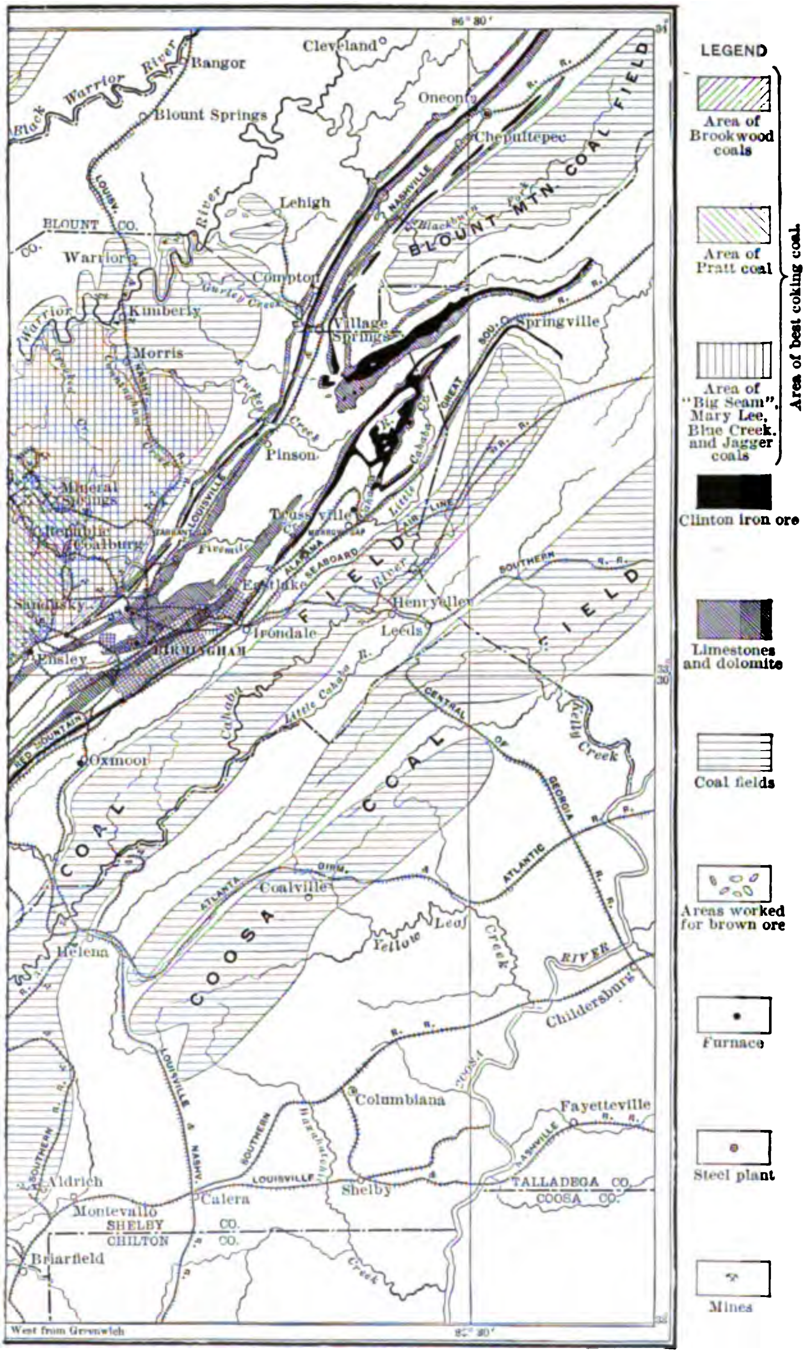

PLATE XXXV. — Geologic map of eastern half of Birmingham, Ala., district. (*After Burchard, Amer. Inst. Min. Engrs., Bull.* 24, 1908.)

having been originally discovered at Clinton, N. Y. It is one of the most persistent iron-ore deposits that is known (Fig. 135), for it occurs at most points where rocks belonging to the Clinton stage of the Silurian are found.

The following districts may be enumerated as showing the location of the more important deposits: (1) west central New York; (2) several narrow belts in central Pennsylvania; (3) Alleghany County, Va.; (4) a belt through Lee and Wise counties, Va., extending southwestward into the La Follette district of Tennessee; (5) narrow belts in the region of Chattanooga, Tennessee; (6) Birmingham, Alabama; (7) Bath County, Kentucky; and (8) Dodge County, Wisconsin. Other known occurrences of minor importance are indicated on the map, Fig. 135, and in addition the ore has been recently discovered by drilling in Missouri.

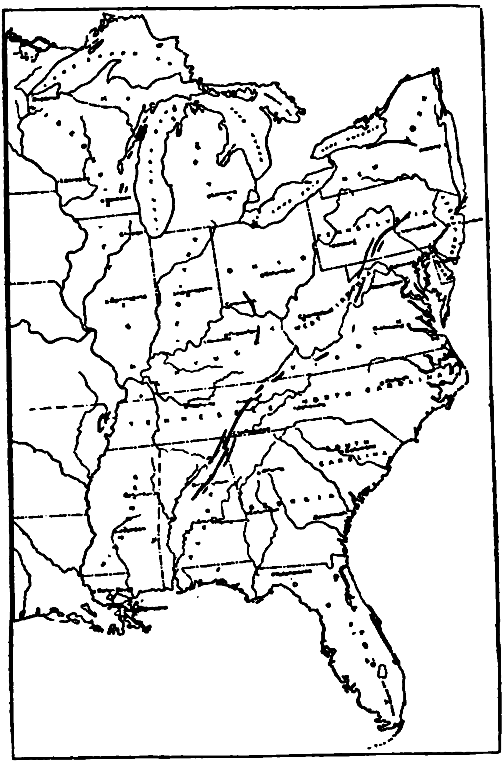

FIG. 135. — Map of eastern United States, showing areas of outcrop of Clinton iron ore. (*After McCallie, Ga. Geol. Surv., Bull.* 17.)

Of all these districts, the Birmingham, Alabama, one is the most important, with Chattanooga, Tennessee, and central New York ranking respectively second and third.

The Clinton ore deposits occur as beds, or lenses, interstratified with shales and sandstones at different horizons in the Clinton, and as many as three or four beds may be present at any one locality. They show extremes of thickness, ranging from a few inches to 40 feet, but rarely exceeding ten feet. The thicker beds often contain sandstone and shale partings, and any bed is sometimes traceable for miles along the outcrop.

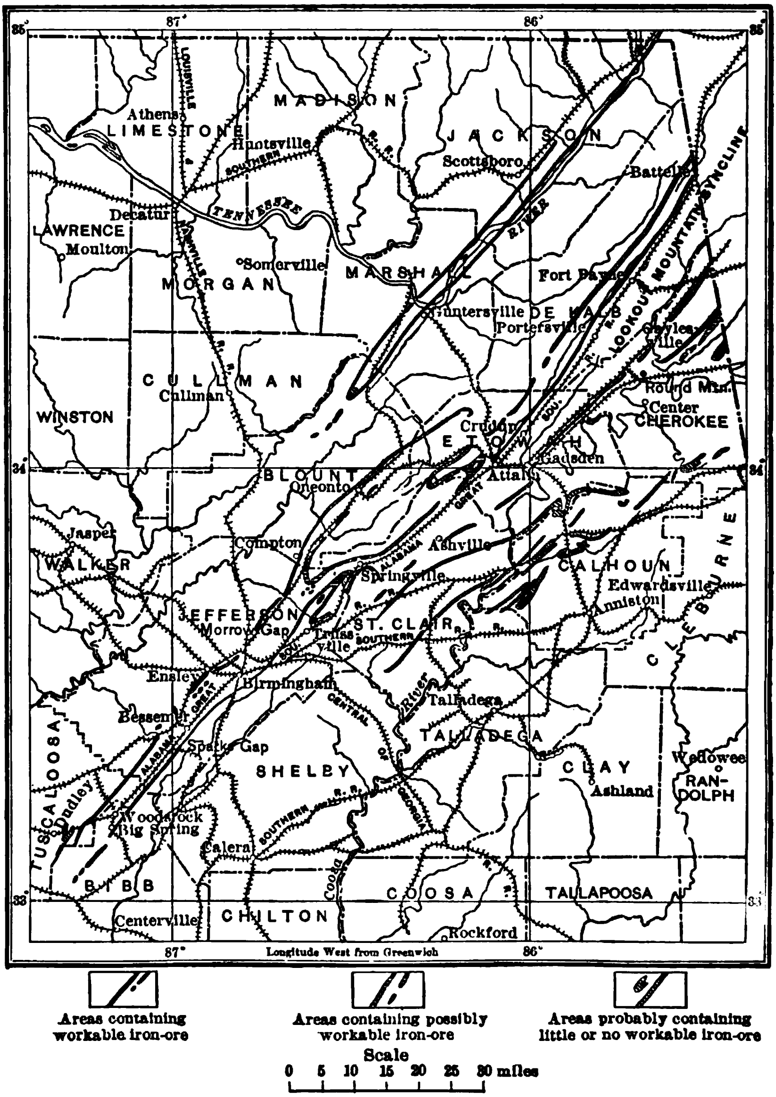

FIG. 136. — Map showing outcrop of Clinton ore in Alabama. (*After Burchard, Amer. Inst. Min. Engrs., Bull.* 24, 1908.)

The dip of the beds depends on the intensity of folding that has occurred in any given area. Thus the ore beds in New York State are nearly horizontal, and can at times be mined for some distance from the outcrop by stripping; while those found in the Appalachian region show a variable and sometimes steep dip, and hence require to be worked by underground methods.

Two textural varieties of Clinton ore are recognized, viz. (1) fossil ore, and (2) oölitic ore.

The former is made up almost entirely of a mass of fossil fragments, while the latter consists of small, rounded grains of concretionary character. These two varieties may occur in the same or separate beds.

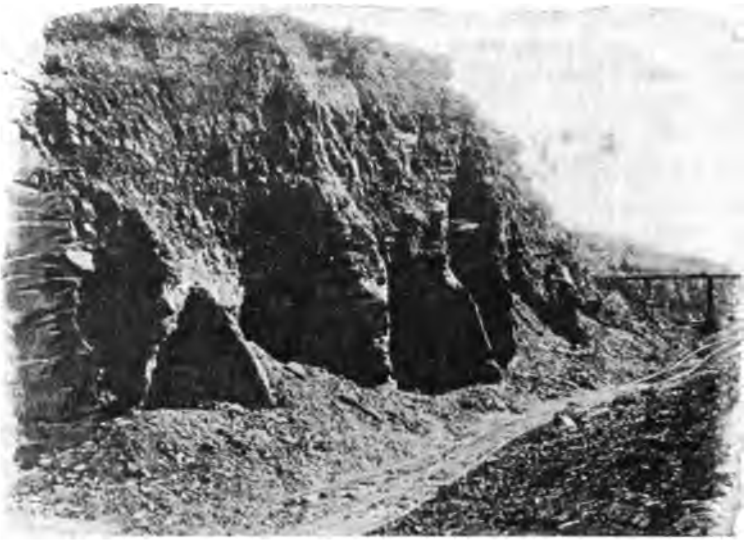

FIG. 137. — Outcrop of Clinton iron ore, Red Mountain, near Birmingham, Ala. (*Photo. from Tennessee Coal and Iron Company.*)

A second classification, based on grade, includes (1) soft ore, and (2) hard ore. The former is found in the outcropping portion of the seam and may extend to variable depths, sometimes as much as 400 feet, while the latter, which is usually sharply separated from the former, occurs lower down. The soft ore runs high in iron and silica, but low in lime, because this has been removed by weathering. The hard ore runs high in lime, but low in silica and iron. Both varieties are high in phosphorus and hence of non-Bessemer grade.

Birmingham, Alabama (51). — The great development of the Birmingham district is due to peculiar local conditions, for we find the iron ores, flux, and fuel all in close proximity to each other (Pls. XXXIV, XXXV).

The Clinton ore beds are found in Red Mountain (Figs. 136, 137) on the east side of the valley in which the city of Birmingham lies. There the Clinton formation, which is 200 to 500 feet thick and dips westward from 20° to 50°, is composed of beds of shale and sandstone and includes four well-marked iron-ore horizons, generally in the middle third of the formation.

These beds are known as the Hickory, Ida, Big, and Irondale seams, but there is difficulty in correlating them in different parts of the field.

Of these four beds the Big and Irondale are the most important. The thickness of the former is estimated at from 16 to 30 feet, but the good ore is rarely more than 10–12 feet thick, and at most places only 7 to 10 feet are mined. In the middle of the district, the bed is separated into two benches by a parting along the bedding plane, or by a shale bed. Either bench, though producing in one part of the district, may grade into shaly low-grade ore in another part.

The following analyses are given by Harder (Min. Res. 1908), to show the gradation from hard ore to soft ore.

Analyses of Clinton Iron Ore from Alabama

	1	2	3	4
Fe	37.00	45.70	50.44	54.70
SiO_2	7.14	12.76	12.10	13.70
Al_2O_3	3.81	4.74	6.06	5.66
CaO	19.20	8.70	4.65	.50
Mn	.23	.19	.21	.23
S	.08	.08	.07	.08
P	.30	.49	.46	.10

The unweathered ore is said by Burchard to range from a richly ferruginous sandstone to a ferruginous-siliceous limestone.

New York (55). — In this state the outcrop of the ore extends across the central and western part of the state (Fig. 138). The whole formation dips gently southward, with a gentle north-south synclinal trough in Cayuga and Wayne counties. Both oölitic and fossiliferous ore are found, and at least two beds, and sometimes four, may be present at any given locality. The ore varies in its richness, and while the deposits are very extensive, they have been but little developed.

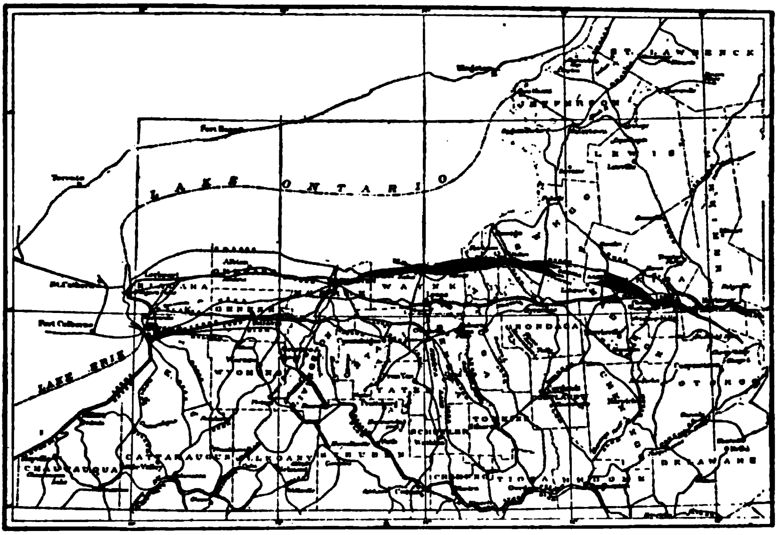

FIG. 138. — Map showing outcrop of Clinton ore formation in New York State. (*After Newland.*)

Analyses of Clinton Ore. — The following are analyses of the Clinton ore from several localities, which serve more to show its variation in character, than as types. Others are given above under Alabama.

	I	II	III	IV	V
Fe	31.3	31.07	54.3	33.341	57.00
P	.24	.69	.462	1.202[3]	.678
SiO_2	23.98	8.56	15.64	1.143	7.12
TiO_2	.225	—	—	—	—
Al_2O_3	7.26	5.04	.89	5.468	—
MnO	—	Tr.	.28	—	.15[4]
CaO	9.15	13.71	1.09	16.56[1]	1.46
MgO	2.92	7.37	.13	9.974[2]	—
SO_3	.987	.072	—	—	—
CO_2	9.6	18.8	None	—	—
H_2O	.26	Undet.	3.07	10.865	—
S	—	—	.03	—	—

I, II, N. Y. State Mus., Bull. 123 : 33, 1908. III. Ga. Geol. Surv., Bull. 17 : 130. IV. U. S. Geol. Surv., Bull. 385. V. U. S. Geol. Surv., Bull. 285 : 188, Alleghany Co., Va.

[1] $CaCO_3$. [2] $MgCO_3$. [3] P_2O_5. [4] Mn.

Origin of Clinton Ore. — The origin of this ore has created considerable discussion, and whatever theory is advanced, it must explain the following features: (1) the fossiliferous character of some beds, (2) the oölitic characters of others, (3) the bedded structure, (4) the soft non-calcareous ore at the surface, and the hard or more calcareous ore at lower levels.

The three theories which have been advanced are the following: (1) original deposition, (2) residual enrichment, (3) replacement. As can be easily seen, the correct solution of the problem is of practical value, since it indicates the possible extent of the ore body.

Residual Enrichment. — This theory supposes that the ore beds represent the weathered outcrops of ferruginous limestones. That is to say, the lime carbonate was leached out by surface waters down to the water level, leaving the insoluble portion carrying the iron, in a more concentrated form. If this theory is correct, then the ore should pass into limestone below the water level.

Russell (57), who was an earnest advocate of this theory, noted that at Attalla, Alabama, the Clinton limestone at a depth of 250 feet from the surface carries only 7.75 per cent of iron, while at the outcrop it has 57 per cent of iron. These figures would seem to bear out this theory, but Eckel (51) has recently claimed that they must be incorrect, as the hard ore at the depth mentioned above carries 38 to 42 per cent of iron. Moreover, in none of the many fairly deep mines in Clinton ore has any change to limestone been noted.

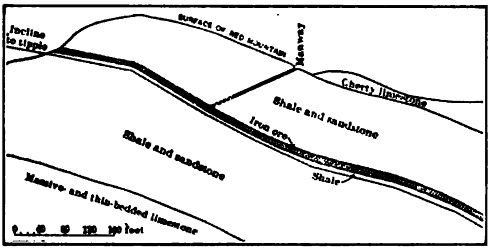

FIG. 139. — Typical profile of slope on Red Mountain, starting on the iron-ore out-crop. Shows bedded character of ore. (*After Burchard, Amer. Inst. Min. Engrs., Bull.* 24, 1908.)

Sedimentary Origin. — This supposes that the ores are of contemporaneous origin with the inclosing rocks, having been deposited on the sea bottom as chemical precipitates.

This view was advocated at an early date by James Hall, who believed that the iron came from the old crystalline rocks, which were leached of their iron contents, the oölitic ore being a chemical precipitate on the ocean floor.

Smyth (59) in amplifying this theory agrees with Hall as to the source of the ore. He points out that during Clinton times the drainage from the crystalline area was carried into a shallow sea or basin. When the iron was carried into these inclosed basins, it was slowly oxidized and precipitated, gathering layer upon layer about the sand grains, thus forming oölitic ore.

Where the ferruginous waters came in contact with shell fragments the iron was precipitated around these, either due to a reaction with the carbonate of lime in the shells, or more often by oxidation. Later both types of deposit became covered by ordinary sediments such as shales, sandstones, or even limestones.

Additional evidence favoring a sedimentary origin is the continuation of the ore with depth, some mines in Alabama being 2000 feet from the outcrop. Moreover some borings in Alabama have struck the ore ½ to 1 mile from the outcrop and 400 to 800 feet below the surface. The occurrence of fragments of ore in the overlying limestone also points to the ore being laid down before the lime rock.

McCallie (54), after studying the Georgia ores, while admitting their sedimentary origin, believes that the original iron mineral was greenalite or glauconite.

Replacement Theory. — This theory assumes that the ores were of much later origin than the inclosing rock, and were formed by the replacement of the lime carbonate by iron, brought in by percolating waters, which had leached the ferruginous constituents from the overlying strata.

The structure of the formations, the comparative absence of iron in the limestone overlying the ore, and restricted vertical range of the ores have been advanced as arguments against this theory.

Rutledge (58), however, as a result of his studies of the Clinton ores of Stone Valley, Pennsylvania, concludes that they represent replacement deposits, and that the only part of the iron content which is of sedimentary character is that contained in the siliceous concretions, most of the iron having come from the shale overlying the ore beds; the hematite deposits have thus been formed by replacement of limestone and concentration of the ore. The evidence presented in favor of this view is: (1) the invariable association of the soft, rich ore with the leached decolorized shales, and of the hard, lean ores with unweathered bright shales; (2) the relations of the ores to the shattered sandstones and to the topographic situation of the ores; (3) the fact that analogous replacements are now taking place in the Medina; (4) the observed progressive steps in the transformation of the limestone to an ore, which may be followed in the field, in thin sections, and in chemical analyses, and (5) the absence of conditions, such as a local crumpling, including a shrinking of the strata, pointing to a relative rather than an absolute enrichment of the ores.

In view of the fact that the advocates of the several theories often bring apparently good evidence to support their case, one may perhaps question whether several different methods of concentration have not been operative. To the author, it seems that the sedimentary mode of accumulation has probably been the dominant one in most cases.

LIMONITE

Limonite (13, 22, *a*, 62–72), or brown hematite, is, like magnetite, of little importance in the United States as compared with hematite, having yielded but 7.2 per cent of the total domestic iron-ore production in 1908.

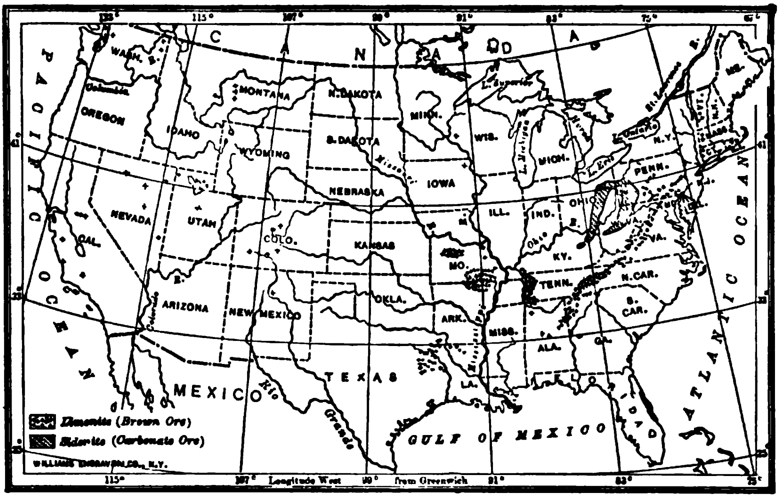

Fig. 140. — Map showing distribution of limonite and siderite in the United States. (*After Harder.*)

Although deposits of limonite are widely scattered over the United States (Fig. 140), about nine tenths of the quantity produced comes from five states, viz., Alabama, Virginia, Tennessee, Georgia, and Pennsylvania; indeed, the first two supply over 50 per cent of the total output.

Limonites are rarely of high purity, mainly because of the fact they are frequently associated with clayey or siliceous matter. This can sometimes be separated to a large extent by washing.

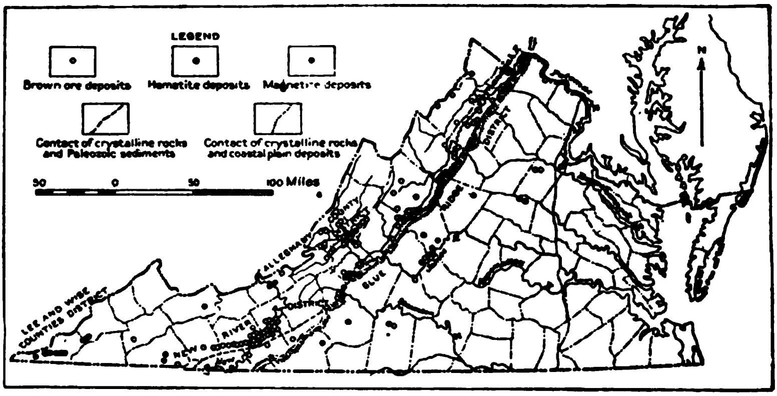
LEGEND
Brown ore deposits
Hematite deposits
Magnetite deposits
Contact of crystalline rocks and Paleozoic sediments
Contact of crystalline rocks and coastal plain deposits
50 0 50 100 Miles
N
LEE AND WISE COUNTIES DISTRICT
NEW RIVER DISTRICT
ALLEGHANY COUNTY
BLUE RIDGE

Fig. 141. — Map showing location of iron-ore deposits in Virginia. (*After Harder, U. S. Geol. Surv., Bull.* 380.)

Plate XXXVI

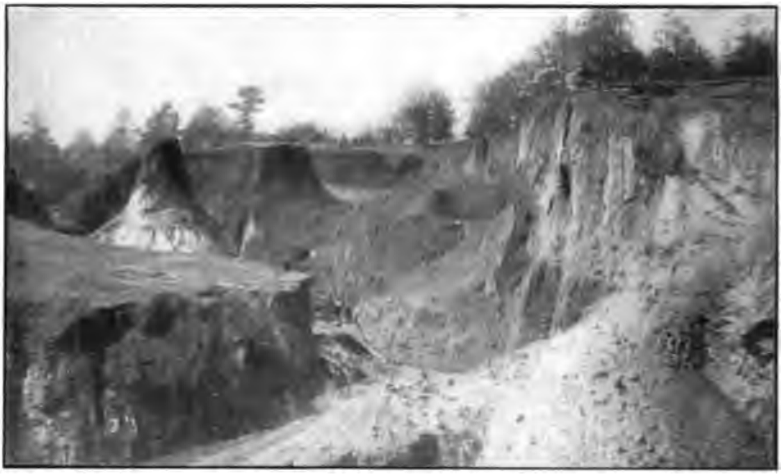

Fig. 1. — Pit of residual limonite, Shelby, Ala. (*After McCalley, Ala. Geol. Surv., Rept. on Valley Regions, Pt. II.*)

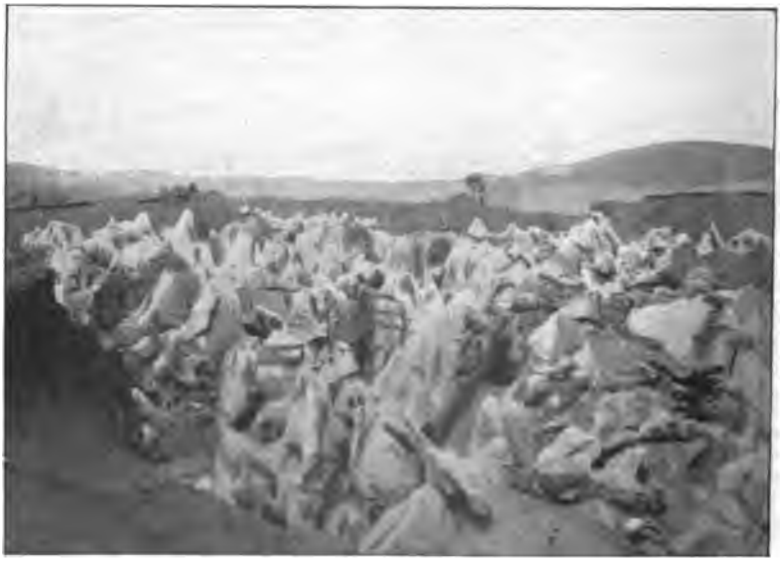

Fig 2. — Old limonite pit, Ivanhoe, Va., showing pinnacled surface of limestone which underlies the ore-bearing clay. The level of surface before mining began is seen on either side of excavation. (*H. Ries, photo.*)

Limonite ores may occur under a variety of conditions and associated with different kinds of rocks, but two important types are those included under the residual class and occurring as irregular lumps and masses in residual clays, or as gossan ores. Other types are replacement deposits, bog ores, bedded deposits of sedimentary character, etc.

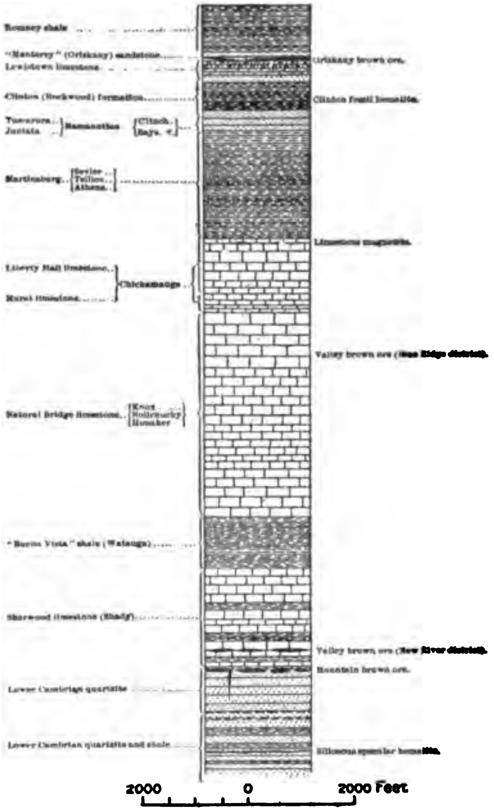

FIG. 142. — Geologic section showing position of iron-ore deposits in Virginia. (*After Watson, Min. Res. Va.*, 1907.)

Residual Limonites. — The residual limonites supply a large percentage of the domestic production, and have been formed (1) by the weathering of pyritiferous sulphide bodies (see gossan), or (2) more often by the weathering of ferruginous rocks.

Gossan deposits (13, 22 *a*). — Limonite gossan ores derived from the oxidation of pyrite, chalcopyrite, and pyrrhotite deposits are found at a number of localities in the crystalline belt of New England and the southern Atlantic states, but they are of limited importance at the present time. One belt of historic and former commercial importance is the "Great Gossan Lead" found mainly in southwestern Virginia (22 *a*), and traceable for over 20 miles, its contents averaging 40 to 41 per cent metallic iron. (See also Ducktown, Tennessee, and Copper in Virginia.)

Limonite gossan ores are not uncommon in many of the western sulphide deposits, and many of them carry more or less manganese oxide, some, as those at Leadville, having sufficient to be used in the manufacture of spiegeleisen. Their main use, however, is as a flux in copper and silver smelting in the western states. The most important ones are in the Black Hills, South Dakota; Leadville, Colorado; Neihart, Monarch, and Elkhorn, Montana; the Tintic district, Utah; Tombstone, Arizona; and Pioche and Eureka, Nevada.

Limonites in Residual Clays. — The other class of residual limonites has many scattered representatives, but the most important ones form a belt extending from Vermont to Alabama (71, 51), and divisible into two groups, viz., the mountain and the valley ores. In these the iron occurs as grains, lumps, or masses scattered through residual clays, associated with Cambro-Silurian limestones, shales, and quartzites.

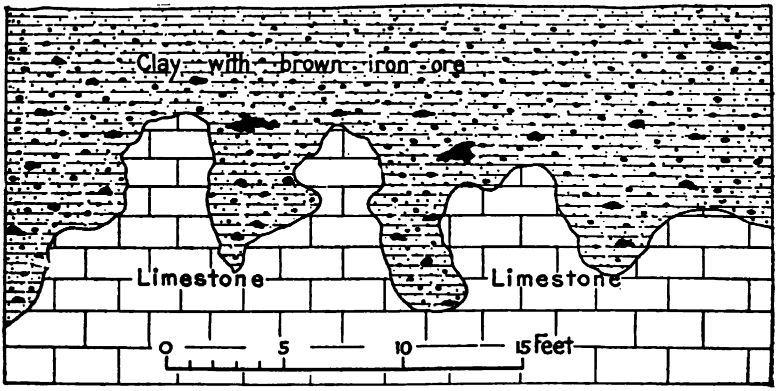

FIG. 143. — Vertical section showing the structure of the valley brown ore deposits at the Rich Hill mine, near Red Island, Va. (*After Harder, U. S. Geol. Surv., Bull.* 380.)

The mountain ores are located in the eastern part of the Appalachian limonite belt, generally in the Blue Ridge or Appalachian Mountains, or at least near their western edge.

The valley ores are closely associated with them on the west, and there is no sharp line of separation between the two. The two types, however, present certain important differences.

Thus the mountain ores usually form relatively small, disconnected pockets in the residual material over the Lower Cambrian quartzite, at or near its contact with the overlying formation, usually a limestone, while other types of less common occurrence are known. The valley ores, on the other hand, form more extensive though shallower deposits in residual clay overlying limestones (Fig. 143) above the quartzite.

In either case, however, the ore is not uniformly distributed through the clay, so that individual pockets soon become worked out, necessitating the finding of a new one.

Mountain ores may extend to a depth of several hundred feet, but the valley ores rarely exceed fifty feet in depth, and in neither case do the deposits as a rule exceed 500,000 tons, the average being 100,000 to 200,000. The ore may form from 5 to 20 per cent of the clay and sand in different deposits or different parts of the same deposit. Limonite and göthite are the two iron-ore minerals, the higher grades carrying as much as 55 per cent metallic iron, but the average shipments run about 45 per cent. The mountain ores are usually poorer than the valley ones, and phosphorus is generally high enough to make the ore non-Bessemer.

The following tables show the percentage range of the chief constituents (Harder) of I, mountain ore, and II, valley ore: —

	I Per Cent	II Per Cent
Fe	35.00–50.00	40.00–56.00
SiO_2	10.00–30.00	5.00–20.00
P	.10–22.00	.05– .50
Mn	.50–10.00	.30– 2.00

While Virginia is the main producer of residual limonites, still Alabama's output is of importance, and some is also obtained from Georgia (67, 72) and Pennsylvania (69).

Origin of the Cambro-Silurian Limonites. — Both the valley and mountain ores are believed to have been formed by the action of weathering.

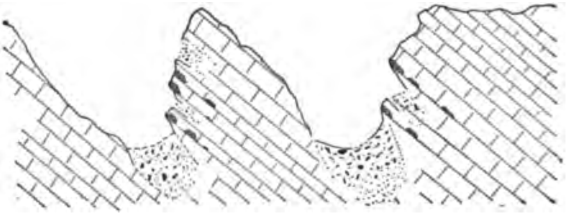

Fig. 144. — Section illustrating formation of residual limonite in limestone. (*After Hopkins, Geol. Soc. Amer., Bull. XI.*)

As the shale and limestones overlying the Cambrian quartzite weathered, the iron oxide was set free, either by the decomposition of ferruginous silicates, or of pyrite or siderite in the limestones. This was then carried downward and concentrated first in the residual clays of the limestone, forming the valley ores. If weathering continued still deeper, the downward percolating iron solutions reached the impervious quartzite, the ores (mountain type) becoming concentrated in the clay overlying this, although some was deposited in crevices in the quartzite.

Oriskany Limonites (22 *a*). — These are so called because of their association with the Oriskany sandstone. To be more exact, they are found in the Lewistown (Silurian) limestone, under the Monterey (Oriskany) sandstone, or the Romney (Devonian) shale. The main producing districts are in Alleghany County, Virginia, and central Pennsylvania, but local deposits are found at the same horizon in West Virginia, Kentucky, and Ohio.

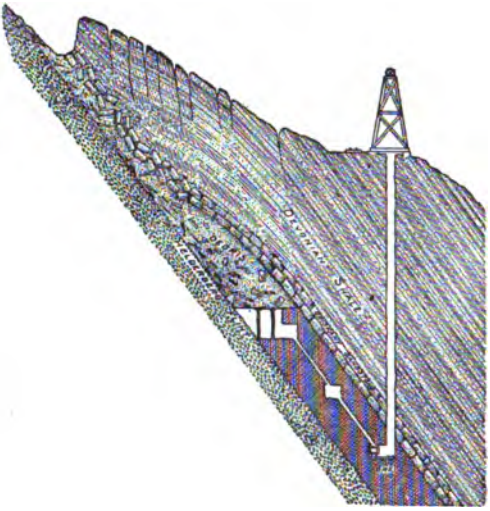

FIG. 145. — Section of Oriskany limonite deposit. (*After Holden, Min. Res. Va.*, 1907.)

The deposits (Fig. 145) form replacements in the upper portion of the Lewistown limestone, and may extend along the strike for a distance of several miles. The thickness and depth are variable, but in some cases may reach 75 feet and 600 feet respectively. The formations in which the ore occurs have been folded and the Oriskany removed from the crests of the folds by erosion, so that the ore is found along the outcrops on the flanks of the ridges.

The Oriskany ore resembles the mountain ore in texture, grade, and impurities, but differs from it in forming larger and more contínous deposits. It shades into limestone with depth.

Other Limonite Deposits. — In northwestern Alabama, western Kentucky, and Tennessee, limonite occurs in residual and sedimentary clays overlying the Mississippian limestone.[1] Brown ore also occurs in the Claiborne (Tertiary) formation of northeastern Texas (65, 70), and adjoining parts of Louisiana and Arkansas. The ore forms horizontal beds, of slight thickness but some extent. It is of little value.

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[1] Burchard, U. S. Geol. Surv., Bull. 315: 154, 1907; and Hayes and Ulrich, Geol. Atlas Folio, 95, 1903.

In the Ozark region of Missouri and Arkansas (73), limonites are found in residual clays over Cambrian limestone, but are of little economic value.

Small deposits are known in Iowa (63), Wisconsin (62), Minnesota, and Oregon (12).

The analyses on page 386 give the composition of limonites from a number of different localities.

The brown ores of the Appalachian belt are much used by pig iron manufacturers because, owing to their siliceous character, they can be mixed with high-grade Lake Superior ores which are deficient in silica. They are also cheaper, and their mixture with other ores seems to facilitate the reduction of the iron in the furnace.

SIDERITE

Siderite (74–78) is the least important of all the ores of iron mined in the United States, both on account of the small extent of the deposits (Fig. 140) and its low iron contents. When of concretionary structure with clayey impurities, it is termed *clay ironstone*, and these concretions are common in many shales and clays. In some districts siderite forms beds, often several feet in thickness, but containing much carbonaceous and argillaceous matter, and is known as *black band ore*. This is found in many Carboniferous shales.

Iron carbonate in bedded deposits is found in the Carboniferous rocks of western Pennsylvania, northern West Virginia, eastern Ohio, and northeastern Kentucky. These ores were formerly the basis of an important iron-mining industry, but little is obtained now except in southeastern Ohio (12).

Concretions and layers of iron carbonate occur in the Cretaceous clays of Maryland (10) and were formerly mined somewhat extensively in the vicinity of Baltimore and Washington. Small deposits are also known in the Chickamauga (Ordovician) limestone of southwestern Virginia (22 *a*). In the western states iron carbonate nodules are found associated with the Laramie (Cretaceous) formation in Colorado and northern New Mexico, but they possess no commercial value (12).

Production of Iron Ores. — The iron-ore mining industry in the United States has progressed with phenomenal strides, and this country now leads the world in the production of iron ore. Indeed so great has the production become that in 1903 it was equal to the combined output of Germany and Luxemburg and the British Empire for 1902. Moreover, the average iron content of the ore mined in the United States is higher than that mined in foreign countries, thereby resulting in the production of a greater amount of pig iron from a given quantity of ore.

Analyses of Limonite

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Fe_2O_3	—	—	62.11	—	—	—	52.86	—	—	—	—	—	—	—
Fe	57.088	29.323	—	49.18	32.59	53.75	—	53.75	36.15	47.00	48.54	47.19	44.68	43.6
MnO_2	—	—	2.85	—	—	—	.61	—	—	—	—	—	—	—
Mn	.504	.33	—	.32	.12	.57	—	.57	1.40	2.70	—	.72	—	.80
SiO_2	5.145	41.575	18.97	13.73	45.24	10.31	33.26	10.31	16.36	12.25	11.22	12.50	18.90	24.00
P_2O_5	—	—	1.10	—	—	—	1.325	—	—	—	—	—	—	—
P	.122	.055	—	.376	.068	.191	—	.191	.12	.85	.38	—	.09	.14
S	.023	.105	.06	—	—	—	.014	—	—	—	.09	—	.20	.018
Al_2O_3	1.471	3.995	2.39	—	6.30	—	5.26	—	—	—	3.61	2.44	5.76	2.3
CaO	.137	1.85	.48	—	—	—	.28	—	—	—	.84	—	.18	.58
MgO	tr.	.776	.42	—	—	—	—	—	—	—	—	—	tr.	.30
P	—	—	—	—	—	—	—	—	—	—	—	.26	—	—
H_2O	11.01	9.67	11.62	10.33	—	10.48	1.90	10.48	—	—	& moist. 13.00	7.10	11.03	—

I. Best ore, Old Hill mine, Salisbury district, Conn., Econ. Geol., II : 171, 1907. II. Poor ore, same mine. *Ibid.* III. Average of 29 commercial analyses of Pennsylvania limonite, Bull. Geol. Soc. Amer., XI : 481. IV. Earthy mountain brown ore, Greenville, Augusta County, Va., U. S. Geol. Surv., Bull. 380 : 222. V. Red shaly mountain brown ore, Buena Vista, Rockbridge County, Va., *Ibid.* VI. Oriskany brown ore, near Low Moor, Alleghany County, Va., *Ibid.* VII. Oriskany brown ore, Covington, Va., U. S. Geol. Surv., Bull. 285 : 187. VIII. Valley brown ore, U. S. Geol. Surv., Min. Res. 1908. IX. Gossan ore, Betty Baker, Carroll County, Va., Min. Res. Va., 1907 : 265. X. Gossan ore, Pittsville, Pittsylvania County, Va., *Ibid.* XI. Average composition, Alabama limonites. XII. Average of Champion area, Birmingham district, Ala., U. S. Geol. Surv., Bull. 400 : 169. XIII. Rusk, Cherokee County, Tex. XIV. Average composition of rock and wash ore, Spring Valley, Wis., Mich. Acad. Sci., 11th Ann. Rept.

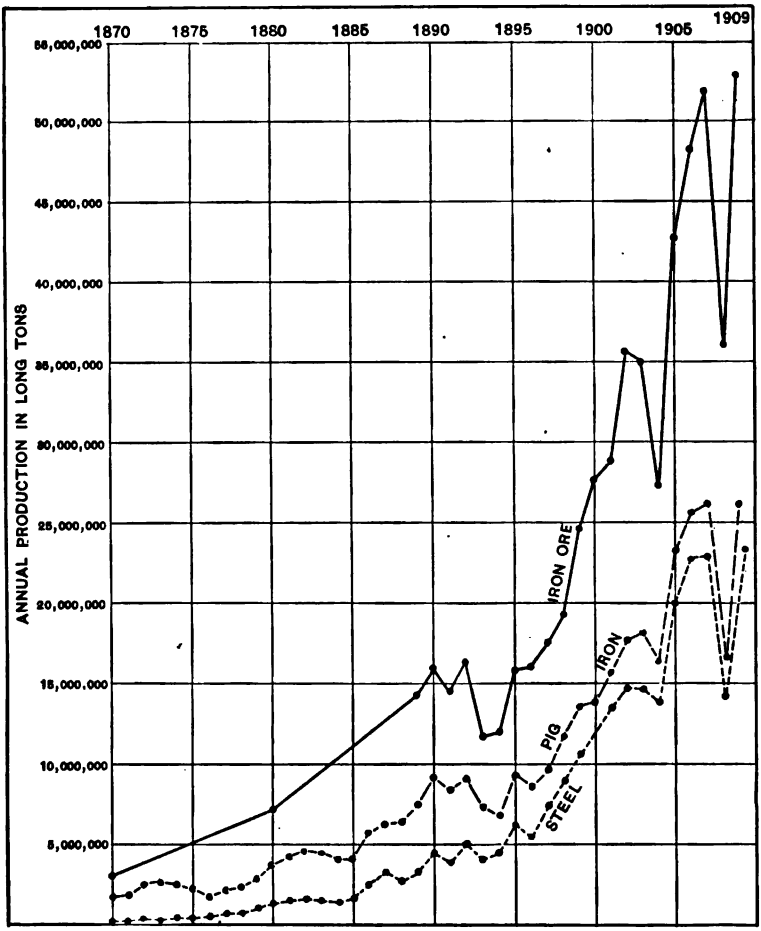

FIG. 146. — Diagram showing the production of iron ore, pig iron, and steel in the United States, 1870 to 1909. (*After Harder.*)

The phenomenal growth of the iron-mining industry is shown in the following table:—

Decade	Quantity	Percentage of Increase
	Long tons	
1870–1879	43,770,527	—
1880–1889	91,043,854	108.0
1890–1899	163,989,193	80.1
1900–1909[1]	[1] 392,000,000	138.0

[1] Approximate.

The Lake Superior region is now producing at least three quarters of the iron ore used in the United States, and it has large reserves of ore, although the high-grade ones are becoming rapidly exhausted. The low-grade ores of this region and others will, however, be available for a much longer time.

While there is not danger of the present supply of ore soon becoming exhausted, still, with the present consumption, it is well to consider possible sources of the future.

In the United States the Utah and some other western deposits will no doubt be drawn upon, and many ores now looked upon as too low grade to work will also be considered. Aside from domestic sources of supply there are foreign ones which may perhaps be eventually turned to, such as those from Canada, Newfoundland, and Brazil on this side of the Atlantic, or even those of Scandinavia on the European side. In the last-mentioned country especially, attention has been drawn in the last few years to magnetite deposits located well within the Polar circle and of stupendous size.

PRODUCTION OF IRON ORES IN THE UNITED STATES FROM 1904 TO 1908 — LONG TONS

	1904	1905	1906	1907	1908
Hematite . .	23,839,477	37,567,055	42,481,375	46,060,486	31,788,564
Brown ore . .	2,146,795	2,546,662	2,781,063	2,957,477	2,620,390
Magnetite . .	1,638,846	2,390,417	2,469,294	2,679,067	1,547,797
Carbonate . .	19,212	21,999	17,996	23,589	26,585
Total . . .	27,644,330	42,526,133	47,749,728	51,720,619	35,983,336

PRODUCTION OF IRON ORE IN THE MORE IMPORTANT STATES FROM 1904 TO 1906

	1904		1905		1906	
	LONG TONS	VALUE	LONG TONS	VALUE	LONG TONS	VALUE
Minnesota	12,728,835	$18,141,902	21,735,182	$35,895,001	25,364,077	$51,799,256
Michigan	7,089,887	13,936,261	10,885,902	23,367,233	11,822,874	31,145,087
Alabama	3,699,881	3,744,350	3,782,831	4,257,155	3,995,098	5,123,539
Wisconsin	483,475	856,710	859,283	1,718,890	848,133	2,033,217
New York	842,303	1,885,291	1,139,937	3,197,919	1,041,992	2,635,639
Virginia	[1] 550,253	[1] 951,478	740,345	1,256,428	828,081	1,579,817
Tennessee	500,982	566,813	734,770	918,850	870,734	1,307,433
Pennsylvania . . .	397,107	611,211	808,717	1,060,162	949,429	1,246,267
New Jersey	499,949	1,126,687	526,217	1,269,374	542,518	1,570,578
Georgia	293,802	356,950	200,842	296,561	411,230	734,780
Missouri	49,285	92,820	[2] 113,112	[2] 162,028	80,910	158,109

[1] Includes West Virginia.

[2] Includes Iowa.

Production of Iron Ore in the More Important States from 1907–1908

	1907		1908	
	Long Tons	Value	Long Tons	Value
Minnesota	28,969,658	$76,668,836	18,652,220	$42,313,974
Michigan	11,830,342	36,441,330	8,839,199	25,150,861
Alabama	4,039,453	4,863,129	3,734,438	4,358,902
Wisconsin	838,744	2,665,737	733,993	2,027,208
New York	1,375,020	2,820,135	697,473	2,098,247
Virginia	786,856	1,538,920	692,223	1,465,691
Tennessee	813,690	1,325,134	635,343	876,007
Pennsylvania	837,287	1,298,717	443,161	572,346
New Jersey	549,760	1,815,586	394,767	1,162,474
Georgia	444,114	837,102	321,060	540,189
Missouri	[1] 111,768	[1] 226,286	98,414	218,182

[1] Includes Iowa.

Production of Lake Superior Iron Ore by Ranges, 1898–1908, in Long Tons

Year	Marquette	Menominee	Gogebic	Vermilion	Mesabi	Total
1898	2,987,930	2,275,664	2,552,205	1,125,538	4,837,971	13,779,308
1899	3,634,596	3,281,422	2,725,648	1,643,984	6,517,305	17,802,955
1900	3,945,068	3,680,738	3,104,033	1,675,949	8,158,450	20,564,238
1901	3,597,089	3,697,408	3,041,869	1,805,996	9,303,541	21,445,903
1902	3,734,712	4,421,250	3,683,792	2,057,532	13,080,118	26,977,404
1903	3,686,214	4,093,320	3,422,341	1,918,584	13,452,812	26,573,271
1904	2,465,448	2,871,130	2,132,898	1,056,430	11,672,405	20,198,311
1905	3,772,645	4,472,630	3,344,551	1,578,626	20,156,566	33,325,018
1906	4,070,914	4,962,357	3,484,023	1,794,186	23,564,891	37,876,371
1907	4,167,810	4,779,592	3,609,519	1,724,217	27,245,441	41,526,579
1908	3,309,917	2,904,011	3,241,931	927,206	17,725,014	28,108,079

Twelve Iron Mines of the United States which produced the Largest Tonnage in 1908

Name of Mine	Locality	Variety of Ore	Production, 1908, Long Tons
Hull Rust	Hibbing, Minn.	Hematite	2,926,614
Burt	do.	do.	1,461,068
Fayal	Eveleth, Minn.	do.	1,450,829
Red Mountain Group	Bessemer, Ala.	do.	1,329,079
Adams	Eveleth, Minn.	do.	781,374
Newport	Ironwood, Mich.	do.	716,365
Norrie	do.	do.	698,345
Virginia	Virginia, Minn.	do.	673,583
Mahoning	Hibbing, Minn.	do.	611,592
Morris	do.	do.	528,169
Pioneer	Ely, Minn.	do.	525,045
Stevenson	Hibbing, Minn.	do.	496,785

Imports and Exports of Iron Ore into and from the United States, 1907-1908

	IMPORTS		EXPORTS	
	Long Tons	Value	Long Tons	Value
1907	1,229,168	$3,937,483	278,608	$763,422
1908	776,898	2,224,248	309,099	1,012,924

World's Production of Iron Ore for 1907

	Tons		Tons
United States	51,720,619[1]	Cuba	658,331[1]
Germany and Luxemburg	27,697,128	Algeria	973,445
Great Britain	15,731,614[1]	Greece	768,863
Spain	9,896,178	Italy	517,952
France	10,008,478	Belgium	316,250
Russia	5,700,000	China	33,306
Sweden	4,480,070	India	67,667
Austria-Hungary	4,356,804	Japan	—
Canada-Newfoundland	887,321[1]	Norway	140,804
		Australia	3000[1]

[1] Long tons; other figures represent metric tons.

Iron-ore Reserves (3). — As a result of the recent agitation over the conservation of our mineral resources, attempts have been made by the United States Geological Survey to estimate the quantity of both at present available and non-available ore still remaining in the ground. That such estimates can only be very approximate is self-evident, partly because the irregularity of most iron-ore deposits makes it difficult to estimate their contents. Bedded ores like those of the Clinton can be most closely figured on, while in the case of the Adirondack ores there may be an error of 15 to 20 per cent.

The estimate of availability is influenced by the cost of ore delivered at furnace, cost of reduction, and accessibility; and any of these factors might change at no distant future.

The metallic iron content of ores now used ranges from about 30 to 65 per cent, this wide variation being due in part to character of other elements in the ore, and in part to favorable location. Thus the Clinton ores, running as low as 30 per cent iron, can be used, because their high lime content makes them practically self-fluxing, but they must be used near the point of production.

Siliceous ores running under 40 per cent iron are not at present available unless located near fuel supplies, because they will not bear the cost of transportation and are expensive to reduce.

ESTIMATES OF IRON-ORE SUPPLIES OF THE UNITED STATES

COMMERCIAL DISTRICTS (STATES)	MAGNETIC ORES			
	NONTITANIFEROUS		TITANIFEROUS	
	Available	Not Available	Available	Not Available
	Long Tons	Long Tons	Long Tons	Long Tons
1. Northeastern	160,000,000	111,500,000	90,000,000	100,000,000
2. Southeastern	[1] 12,500,000	23,000,000	——	——
3. Lake Superior	——	4,500,000,000	——	25,000,000
4. Mississippi Valley	——	——	——	——
5. Rocky Mountain	[1] 51,485,000	[1] 115,440,000	——	1,500,000
6. Pacific Slope	[1] 68,950,000	11,800,000	——	2,000,000
	292,935,000	4,761,740,000	90,000,000	128,500,000

COMMERCIAL DISTRICTS (STATES)	HEMATITE ORES			
	SPECULAR AND RED		CLINTON	
	Available	Not Available	Available	Not Available
	Long Tons	Long Tons	Long Tons	Long Tons
1. Northeastern	2,000,000	2,000,000	35,000,000	620,000,000
2. Southeastern	8,000,000	53,000,000	463,540,000	970,500,000
3. Lake Superior	3,500,000,000	67,475,000,000	10,000,000	30,000,000
4. Mississippi Valley	15,000,000	10,000,000	——	——
5. Rocky Mountain	4,275,000	2,100,000	——	——
6. Pacific Slope	——	10,000,000	——	——
	3,529,275,000	67,552,100,000	508,540,000	1,620,500,000

[1] Includes some hematite.

COMMERCIAL DISTRICTS (STATES)	BROWN ORES		CARBONATE ORES		TOTAL SUPPLIES	
	Available	Not Available	Available	Not Available	Available	Not Available
	Long Tons	Long Tons	Long Tons	Long Tons	Long Tons	Long Tons
1. Northeastern	11,000,000	13,500,000	——	248,000,000	298,000,000	1,095,000,000
2. Southeastern	54,400,000	168,000,000	——	62,000,000	538,440,000	1,276,500,000
3. Lake Superior	——	——	——	——	3,510,000,000	72,030,000,000
4. Mississippi Valley	300,000,000	560,000,000	——	——	315,000,000	570,000,000
5. Rocky Mountain	2,000,000	1,625,000	——	——	57,760,000	120,665,000
6. Pacific Slope	——	105,000	——	——	68,950,000	23,905,000
	367,400,000	743,230,000	——	310,000,000	4,478,150,000	75,116,070,000

1. Vermont, Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Maryland, Ohio.
2. Virginia, West Virginia, eastern Kentucky, North Carolina, South Carolina, Georgia, Alabama, east Tennessee.
3. Michigan, Minnesota, Wisconsin.
4. Northwest Alabama, west Tennessee, west Kentucky, Iowa, Missouri, Arkansas, east Texas.
5. Montana, Idaho, Wyoming, Colorado, Utah, Nevada, New Mexico, west Texas, Arizona.
6. Washington, Oregon, California.

So, too, the amount of other constituents present, such as phosphorus, sulphur, copper, chromium, manganese, and alumina, exert a determining influence on the cost of production and quality of the iron.

Two tendencies are noticeable in the iron industry of the present day, viz., the use of ores with a lower average iron content, and the decentralization of the iron industry.

This involves a corresponding increase in the cost of transportation per unit of iron, and an increase in the proportion of fuel which goes to the ore-producing region. An accompaniment of this will be the general adoption of by-product coking, and Hayes points out that in certain furnaces now operating in the Lake Superior district the profit corresponds approximately to the value of the by-products from the coke ovens.

The table on page 391 gives a summary of Hayes' estimates of domestic iron ore reserves by commercial districts and varieties of ores.

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CHAPTER XVI

COPPER

Ore Minerals of Copper. — Copper-bearing minerals are not only numerous, but widely though irregularly distributed. More than this, copper is found associated with many different metals and under varied conditions.

Nevertheless but few copper-bearing minerals are important in the ores of this metal, and the number of important producing districts is comparatively small.

The ore minerals of copper together with their theoretic composition and percentage of copper are as follows: —

ORE MINERAL	COMPOSITION	PER CENT CU.
Chalcopyrite	$CuFeS_2$	24.5
Chalcocite	Cu_2S	79.8
Bornite	Cu_3FeS_3	55.58
Enargite	$3\,Cu_2S,\ 2\,As_2S_3$	48
Covellite	CuS	66.5
Tetrahedrite	$Cu_8Sb_2S_7$	30.40
Tennantite	$Cu_8As_2S_7$	57
Native copper . . .	Cu	100
Azurite	$2\,CuCO_3,\ Cu(OH)_2$	61
Malachite	$CuCO_3,\ Cu(OH)_2$	62
Chrysocolla	$CuSiO_3,\ 2\,H_2O$	45.2
Cuprite	Cu_2O	88.8
Melaconite	CuO	79.84
Brochantite	$CuSO_4,\ 3\,Cu(OH_2)$	62.42
Atacamite	$Cu(OH)Cl,\ Cu(OH)_2$	59.45
Chalcanthite	$CuSO_4,\ 5\,H_2O$	25.4

In the unaltered portion of the ore body the copper compounds are mainly sulphides, but arsenides and antimonides are also known. In the gossan the copper occurs as carbonates, sulphates, silicates, oxides, native, and more rarely as phosphates, arsenates, antimonates and vanadates.

Gangue Minerals. — Quartz is the commonest gangue mineral, but calcite and siderite are abundant in a few; barite, rhodochrosite, and fluorite are also known. Sericite is found in some veins, and so is tourmaline in certain tin-copper and gold-copper ones.

Metallic impurities may be present which cause trouble in the reduction of the ores. Of these zinc is the most objectionable, but bismuth, though rare, is also very undesirable, but can be eliminated by electrolytic refining. Arsenic, antimony, tellurium, and selenium are partially eliminated in smelting, but must be completely removed by electrolytic methods to make the copper pure enough for electrical work.

Tellurium is not uncommon in some districts, and renders the metal red-short even in small amounts. Silver, even if present in as small amounts as .5 per cent, lowers the electric conductivity, and above 3 per cent affects the toughness and malleability of the copper. Sulphur up to .25 per cent lowers the malleability and .5 per cent renders the metal cold-short, while .4 or more per cent phosphorus makes it red-short.

A high percentage of silica is detrimental, as it requires too much basic flux.

Most of the copper ores now worked are of low grade, but can be profitably treated because of the extent of the operations and possibility of concentration. Occasionally low-grade ores are found which are self-fluxing, as those of the Boundary District of western Canada. The introduction of pyritic smelting has permitted the profitable treatment of low-grade pyritic-copper ores, even if they carry no gold or silver. Complex ores of copper, lead, and zinc sulphides are more costly to treat, but this expense may be more than made up for by their gold and silver contents.

Very few ores approach the theoretic percentages given above. Thus in Michigan, where native copper is the ore mineral, this as now mined rarely averages above 1 per cent metallic copper, and may fall as low as .6 per cent. At Butte, Montana, the copper-bearing minerals are chalcocite, enargite, bornite, and chalcopyrite, but much of the ore does not usually contain more than 5 or 6 per cent metallic copper, and in rarer instances 12 per cent.

Copper ores are found in many formations ranging from the pre-Cambrian to the Tertiary, but grouped according to their mode of origin they fall mostly into one of the four following groups (2): —

1. Magmatic segregations. No workable deposits of this type are known in the United States, but primary chalcopyrite is known to occur in some localities.

2. Contact-metamorphic deposits, in crystalline, usually garnetiferous limestone, along igneous rock contacts. (Clifton-Morenci district, Arizona; Bingham Cañon, Utah, etc.)

3. Deposits formed by circulating, usually ascending and probably hot waters, the ores being deposited in fissures, pores, spaces of brecciation, or sometimes by replacement of the rock.

4. Pod- or lens-shaped deposits in crystalline schists, which may

represent concentration of material from a disseminated condition in the surrounding rocks, or in some cases are thought to be metamorphosed contact deposits.

While the third and fourth groups include all the largest deposits of the world, still these in all cases do not owe their economic importance to the mode of formation, but rather to secondary changes which have taken place in them, resulting in a leaching of the copper in the upper part of the mass, as copper sulphate, and its transference to lower levels, where it is redeposited through the influence of copper sulphide, iron compounds, or limestone.

Superficial Alteration of Copper Ores (3, 18). — This may produce results of great economic importance, and excellent examples of it are seen in some of the Arizona ores, where the upper portions of the copper deposits are brown or black ferruginous porous masses, brightly colored with oxidized copper minerals such as cuprite, malachite, azurite, and chrysocolla, while below this at a variable depth they pass into sulphides.

In weathering, the copper minerals, such as chalcopyrite or other sulphides, are usually oxidized first to sulphates, and subsequently changed to oxides, carbonates, or silicates, and occasionally even to chlorides and bromides. A concentration of the ore deposit may take place partly by segregation and partly by leaching, and pockets of the ore form, which are surrounded by oxidized iron minerals forming part of the gangue.

While the oxidation will not increase the total copper contents of the ore body, still it may change it into a more concentrated form, for the carbonates and other oxidized copper minerals contain more copper than the original sulphide. The ore in the gossan may therefore run from 8 to 30 per cent or more, while below it may show only 5 per cent of copper (see Penrose under ore deposit refs.). These altered ores cannot, however, be more cheaply treated. If leaching follows oxidation, the gossan may be freed of its ore, as at Butte, Montana, where the upper part of the ore-bearing fissures is poor siliceous gangue. Secondary enrichment may also occur below the water level, giving chalcocite, chalcopyrite, and bornite of later origin.[1]

Distribution of copper ores in the United States (Fig. 147). — About 80 per cent of the copper produced in the United States in 1908 was obtained from three states, viz. Arizona, Montana, and Michigan, named in the order of their output, nearly all of the rest coming from the Appalachians and Cordilleran area; the ores of the latter are often worked chiefly for their gold contents, with copper as a secondary product.

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[1] Both chalcopyrite and bornite are often regarded as primary sulphides.

Only the more important districts can be taken up here, these being representative, however, of several different types of occurrence.

Montana (46–50). — The mining camp of Butte, which is not only the most important district in the state, but probably also the greatest copper producer in the world, lies in southwestern Montana, and in the central part of the Rocky Mountain region.

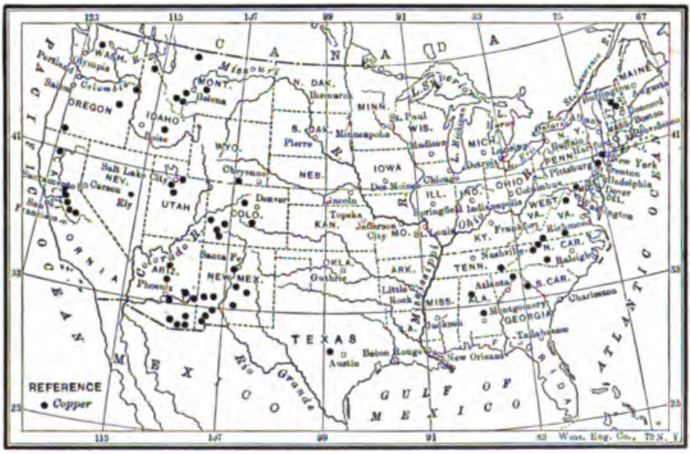


Fig. 147. — Map showing distribution of copper ores in the United States. (*Adapted from Ransome, Min. Mag., X.*)

The ores are mainly secondary sulphides occurring in fissure veins (Figs. 148, 150) formed by replacement along shear zones in Tertiary igneous rocks, and while copper veins are the most important, the district also contains argentiferous ones.

The Tertiary igneous rocks (Figs. 149, 150), named in their order of formation, include: (1) a dark basic granite or quartz monzonite, known as the Butte granite; (2) dikes and irregular intrusions of a white aplite, termed the Bluebird granite; (3) a quartz porphyry cutting both granites; (4) rhyolite of both intrusive and extrusive character, dikes of which cut the ore veins.

There are also some lake beds, and the Butte granite is surrounded by sediments and partly covered by an earlier andesite, but the last two do not appear in the ore district.

The rocks of the district are cut by many joints, belonging to three systems, viz. an east-west, northwest-southeast, and northeast. The first series is displaced by both of the later ones, and while the fissures of the first two series are heavily mineralized, the third carries but little endogenous ore.

The copper veins, which are mainly replacements along fissures in the sheeted granite, and were first worked for silver, consist in in their upper part (200 to 400 feet) of iron-stained quartz with but little copper, while below this are found chalcocite, enargite, bornite, cupriferous pyrite, and more rarely covellite and tetrahedrite.

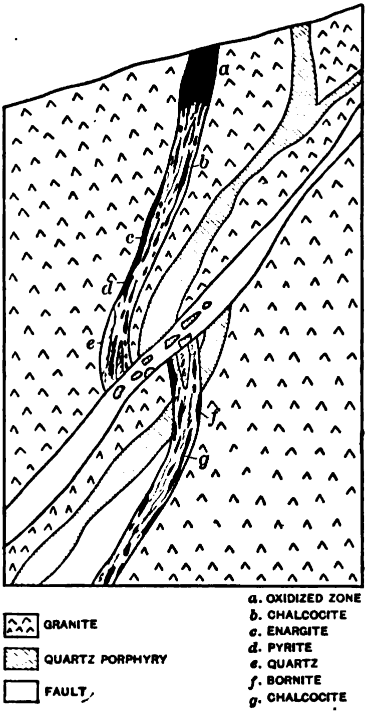


FIG. 148. — Section at Butte, Mont., showing mode of occurrence of ore. (*After Winchell, Eng. and Min. Jour., LXXVIII.*)

Of these the chalcocite forms more than 50 per cent of the ores of the camp, and the enargite a good deal less than one half, while the bornite and cupriferous pyrite sometimes form a noticeable proportion of the ore.

The concentrates average about 8 per cent, and the richness of the ore in any one mine may vary from year to year. Thus in one mine the first-class ore averaged about 8 per cent in 1905 and 1906, while in 1908 and 1909 it exceeded 21 per cent copper.[1]

The ores contain about 2¼ cents of gold and .0375 ounces silver per pound of copper. Arsenic is present, but is not saved, and tellurium is also said to occur in very small amounts (Weed).

Quartz is the gangue in all.

It is supposed that in the copper veins the hot ore-bearing solutions ascended the fractures in the granite, replacing the rock by ore, and resulting in an intense alteration of the walls; the hornblende and mica were changed to pyrite, and the feldspar to sericite and quartz.

While the primary ore was chalcopyrite and pyrite, the enormous secondary bodies of chalcocite have made the district famous. The enargite appears to increase with depth.

[1] A. H. Wethey, private communication.

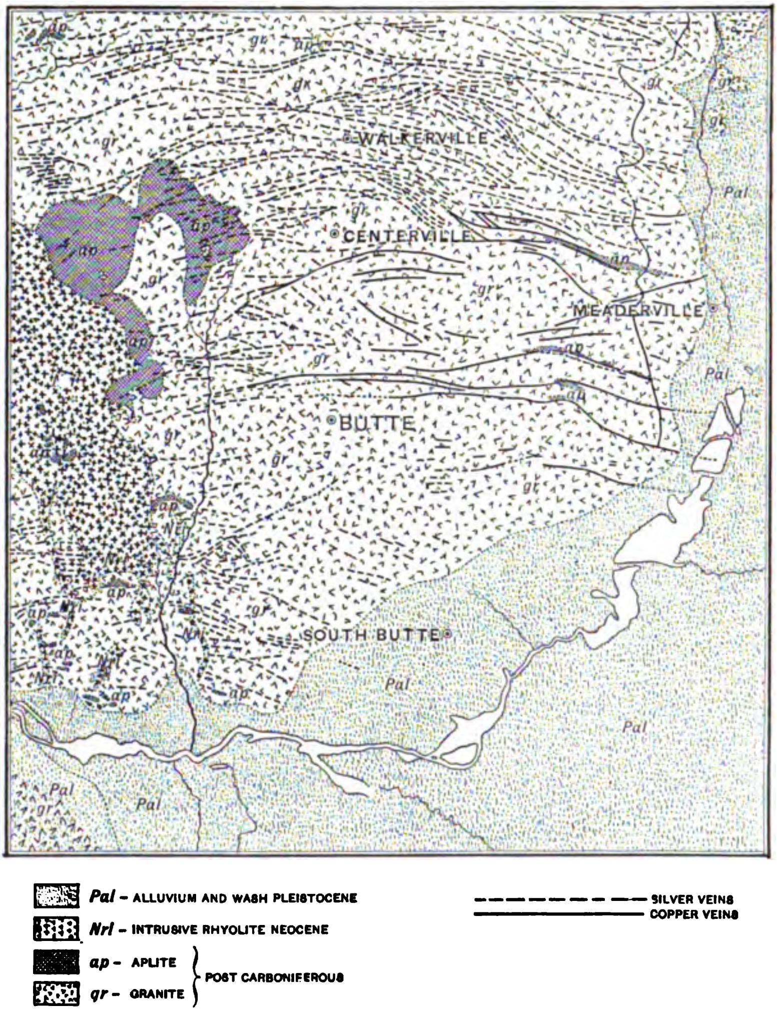


Fig. 149. — Map of eastern part of Butte, Mont., district showing distribution of veins, and geology. (*U. S. Geol. Surv.*)

The veins exhibit a curious uniformity of direction (Fig. 149), most of them striking nearly east and west, and few of them departing more than 15° to 20° from the vertical; still they show considerable variation in width, ranging from a few feet to 50, or even 150 where the altered country rock is impregnated with glance. Unfortunately, the complexity of the veins and uncertainty of boundaries has given rise to much costly litigation in the district.

Plate XXXVII. — View of Anaconda group of mines, Butte, Mont. (*After Weed, Min. Mag., X.*)

The silver veins, which are of subordinate importance, surround the copper deposits on the north and west, and while formed by magmatic waters like the copper deposits, differ from them in being fissure fillings with a characteristic crustified structure, as well as in

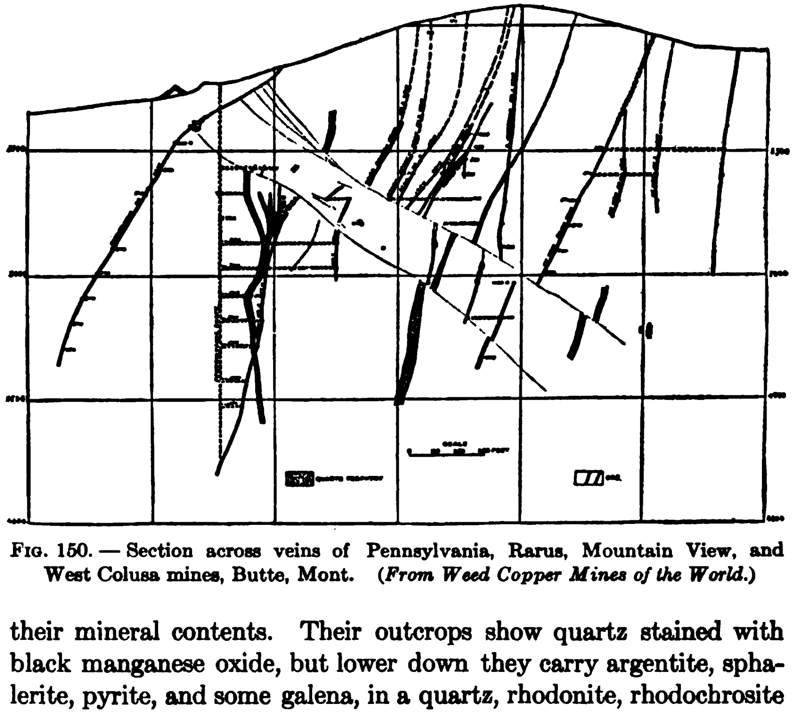


Fig. 150. — Section across veins of Pennsylvania, Rarus, Mountain View, and West Colusa mines, Butte, Mont. (*From Weed Copper Mines of the World.*)

their mineral contents. Their outcrops show quartz stained with black manganese oxide, but lower down they carry argentite, sphalerite, pyrite, and some galena, in a quartz, rhodonite, rhodochrosite gangue.

The history of this mining camp is full of interest. Butte in 1864 was a gold camp, but difficulties in working the gravels directed attention to the mineral-vein outcrops, and unsuccessful attempts were made to work their copper and silver contents, so that it was not until 1875, following a period of quiescence, that the discovery of rich silver ore in the Travona lode revived the mining industry of Butte. In 1877 several silver mines were opened, followed by others; but this did not last many years, for with the drop in the price of silver many mines closed, although one, the Bluebird, had produced 2,000,000 ounces of silver from 1885 to 1892.

The copper mines were worked to only a limited extent at first, and the industry did not assume permanence until 1879–1880, when matte smelting was introduced. In 1881 the Anaconda mine, which was first worked for silver, began to show rich bodies of copper ore, and since then the output of copper has steadily increased, there being a number of large smelting plants distributed between Butte, Anaconda, and Great Falls.

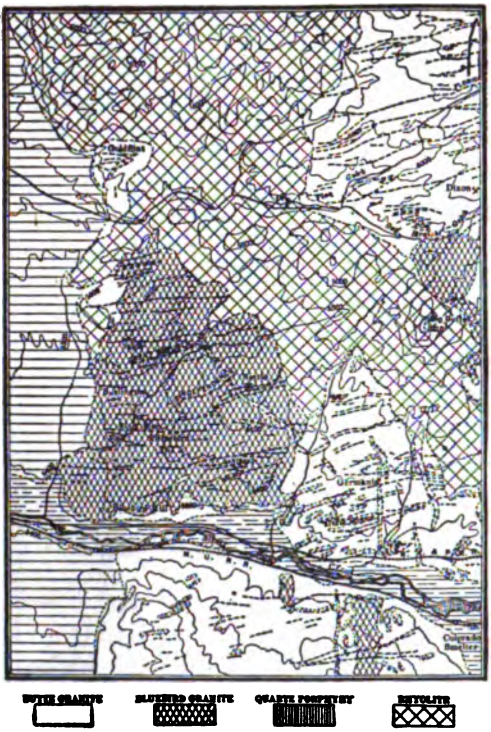
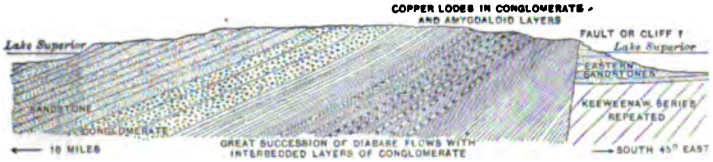


FIG. 151. — Geologic map of western half of Butte district. (*U. S. Geol. Surv.*)

W. H. Weed has estimated that up to January 1, 1897, the district had yielded 500,000 ounces of gold, 100,000,000 ounces of silver, and 1,600,000,000 pounds of copper. In 1887 Butte passed the Lake Superior District in the production of copper, and has kept ahead of it ever since, having in 1903 produced 38.9 per cent of the United States production. In 1907 it was passed by Arizona, and remained in second place in 1908, when it produced 252,503,651 pounds of copper, or 26.6 per cent of the total output of the United States.

Michigan (35–43). — This region, which was discovered in 1830 by Douglas Houghton, has become one of the most famous, as well as one of the leading, copper-producing districts of the world.

The rocks of the region, known as the Keweenaw series, consist of interbedded lava flows, sandstones, and conglomerates, the latter being rounded fragments of igneous rocks, mainly reddish-quartz porphyry.


COPPER LODES IN CONGLOMERATE AND AMYGDALOID LAYERS
Lake Superior
FAULT OR CLIFF ?
Lake Superior
EASTERN SANDSTONES
KEEWEENAW SERIES REPEATED
SANDSTONE
CONGLOMERATE
← 10 MILES
GREAT SUCCESSION OF DIABASE FLOWS WITH INTERBEDDED LAYERS OF CONGLOMERATE
→ SOUTH 45° EAST

GEOLOGICAL CROSS-SECTION OF THE COPPER MINING REGION

FIG. 152. — Section across Keweenaw Point, Mich. (*After Rickard.*)

This series of beds, whose entire thickness may be from 25,000 to 30,000 feet, dips westward (Fig. 152) from 35 to 70 degrees, being overlain conformably on the west by sediments, while on the east they are faulted up against the horizontal Potsdam sandstones.

These beds form a belt 2 to 6 miles wide, which extends from Houghton to the end of the Keweenaw peninsula, and rises as a ridge from 400 to 800 feet above the lake (Pl. XXVIII).

The ore, which is native copper, and is occasionally associated with native silver, occurs (1) as a cement in the conglomerate of porphyry pebbles, or replacing the latter; (2) as a filling in the amygdules of the lava beds (Fig. 154), (3) as masses of irregular and often large size, in veins with calcite and zeolitic gangue.

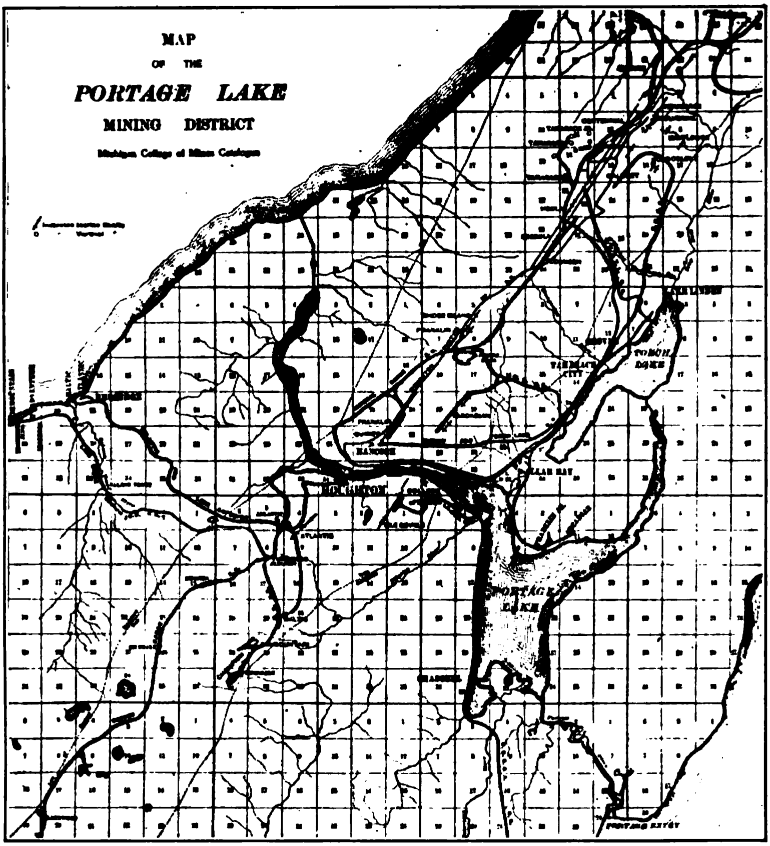


FIG. 153. — Map of a portion of the Michigan copper district, showing strike of lodes.

The tilting of the beds has been accompanied by some slipping and cross faulting, and the presence of copper in cross joints and slip planes indicates later deposition.

The veins, which cut both the igneous and sedimentary rocks, have yielded much copper in former years, and the large masses obtained from them have made the region famous; but at the present time most of the production comes from the Calumet conglomerate, while the balance comes from two other copper-bearing conglomerates known as the Albany and the Allouez, and from the ashbeds and amygdaloids, whose gas cavities are filled with a mixture of native copper, calcite, and zeolites.

A curious and hitherto unexplained feature is the irregular distribution of the copper in the different beds, which may be due to the copper solutions being directed by certain joints or slip planes. Thus the Calumet conglomerate carries practically no ore outside of the Calumet and Hecla ore shoot, which is three miles long, 12–15 feet thick, and has been mined to a depth of 5000 feet.

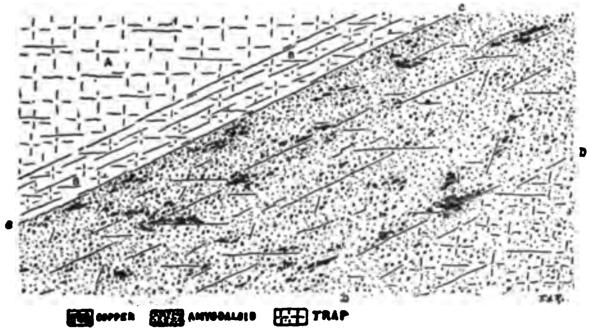


FIG. 154. — Section showing occurrence of amygdaloidal copper, Quincy Mine, Mich. (*After Rickard, Eng. and Min Jour., LXXVII.*)

Various theories have been brought forward to account for the origin of the copper ores in this region.

The diabase was looked upon by Pumpelly as a possible source of the ore, and since its extensive alteration was no doubt accompanied by the oxidation of protoxides, this might account for the reduction of copper mineral to the native or metallic condition, it being known that ferrous salts may precipitate metallic copper (1). More recently Lane (39, 40) has suggested that originally buried water has also been an important factor in concentration, but agrees that the final precipitation was by water working downward.

Lane has pointed out that the mine waters show a striking increase in chlorine with depth, in fact there is more than enough to satisfy the sodium present, and it is contained in relatively large amounts of calcium chloride. Moreover, the molecules of sodium chloride decrease steadily with depth, while those of calcium chloride increase.

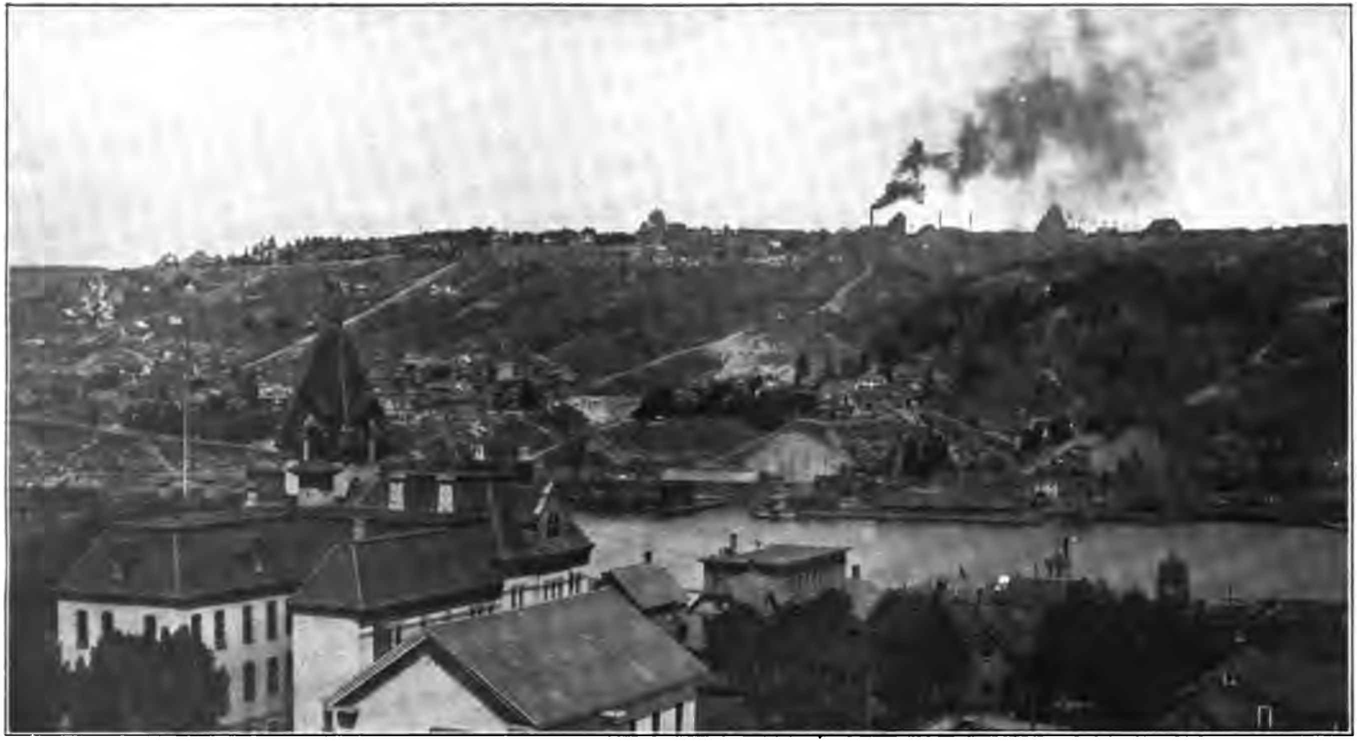


Plate XXXVIII. — View from Houghton, Mich., looking towards Hancock, and showing a portion of the ridge under which the copper deposits lie.

He therefore suggests, and his views are backed by chemical experiments, that the basalt flows originally contained small percentages of copper; that while still heated they no doubt absorbed sea water charged with sodium chloride, and in later times atmospheric waters not containing any, but obtaining it as they seeped through the rocks.

These waters, rich in NaCl, migrated downward, taking copper in solution as copper chloride.

Reactions with the glassy base or original minerals of the volcanic rocks gave rise to the formation of sodium silicates, accompanied by precipitation of copper and formation of calcium chloride. Descending solutions from wide areas became concentrated along lines favorable to underground circulations, and hence shoots of relative richness resulted. It is supposed that certain faults and slips guided these waters.

The theory, although reasonable and backed by laboratory experiments (2), may not be universally accepted, and some observers believe that these deep-seated waters with their peculiar composition are very likely of magmatic origin.

Although these deposits have been worked in prehistoric times, as evidenced by copper implements and ornaments found in the mines, the famous Calumet and Hecla Mine was not opened up until 1846. In 1847 Michigan produced 213 long tons of the total United States production of 300 tons of copper. Since 1863 the annual output has exceeded 1000 tons and gradually and steadily increased up to 1905 when it reached 230,287,992 pounds. In 1908 the production had dropped to 222,289,584 pounds.

Up to 1905 Michigan ranked second in the list of producing states, but in 1906 dropped to third place.

The ores from this district, which are known as Lake ores,[1] are all of low grade, but the deposits are of great extent and rather uniform mineralization, and this fact, together with the possibility of high concentration and low cost of refining, makes it possible to work these low-grade deposits at a profit.

The richest ore now mined contains under 2 per cent of copper, while the poorest runs but little over .5 per cent.

The crushed and concentrated material carries about 65 per cent copper, and this passes through a combined smelting and refining process.

That portion of the copper which contains enough silver to make its recovery profitable, and some which runs too high in impurities for certain uses, is refined electrolytically. The amount so treated has been lessened, owing to a recent demand for copper carrying arsenic. The average recovery of silver per ton of rock mined was .023 ounce.

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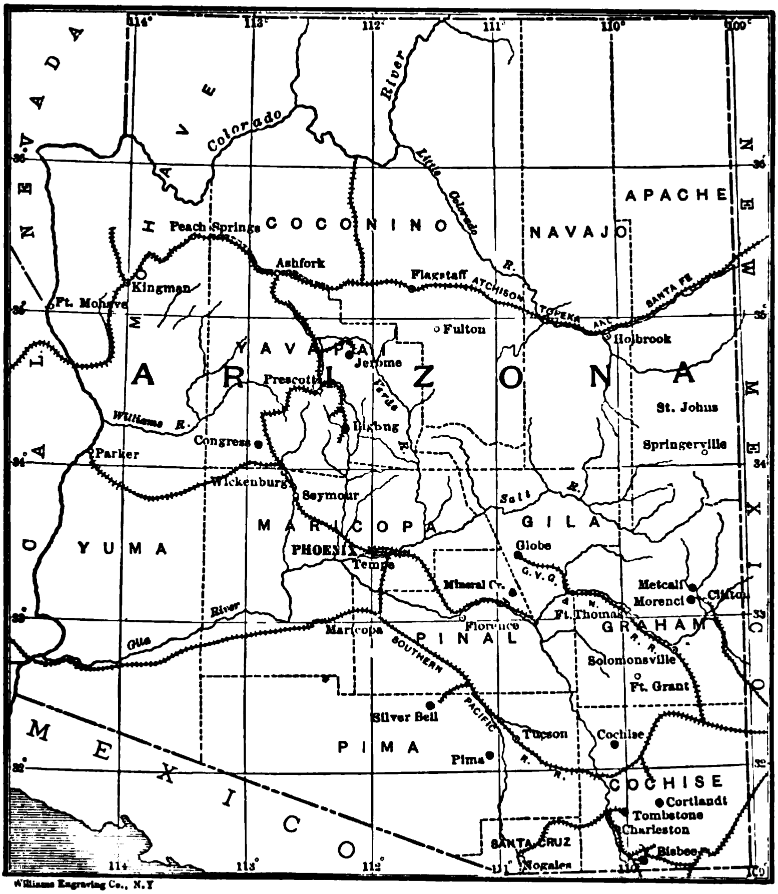
[1] The term has now lost its original meaning, since copper from western states is brought to Michigan for refining and sold as Lake ore.

Arizona (14–21). — This territory in 1908 ranked first as a producer of copper ores in the United States, and has in the past differed from most other copper-producing localities in supplying chiefly ores of oxidized character; in fact, from 1880 to 1895 Arizona was the only copper area in the world whose ores were exclusively oxidized.

The territory (Fig. 155) contains four important districts, all lying within the mountain region, and a fifth one of probably considerable importance. These are: (1) Bisbee or Warren, (2) Jerome or Black Range, (3) Clifton-Morenci, (4) Globe, and (5) Mineral Creek or Ray. The 1st, 3d, and 4th possess certain similarities in the mode of occurrence of the ore.



Williams Engraving Co., N.Y

FIG. 155. — Map of Arizona, showing location of more important mining districts. (*After Lindgren.*)

Bisbee or Warren District (20). — This district, which contains the famous Copper Queen Mine, lies on the eastern slope of the Mule Pass Mountains (Fig. 155), but a short distance from the Mexican boundary. The section at that locality involves strata from pre-Cambrian to Cretaceous age, with an important unconformity between the Carboniferous and Cretaceous (Fig. 157). Prior to the deposition of the latter the rocks had been broken by numerous faults (Fig. 156), one of these, the Dividend fault, being specially prominent in forming one boundary of the ore-bearing area. This was followed by intrusions of a granite magma forming dikes, sills, or irregular stocks, which have metamorphosed the Carboniferous limestones, with the production of characteristic contact minerals.

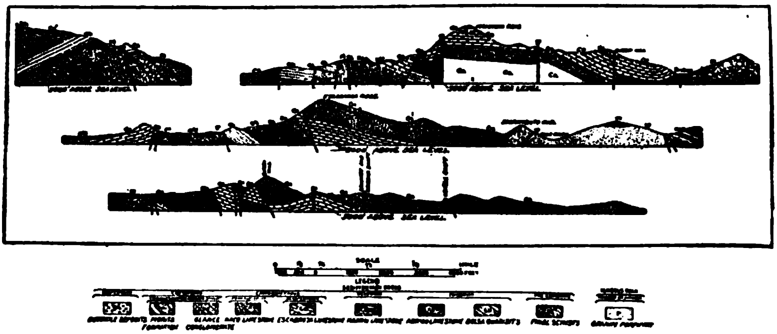
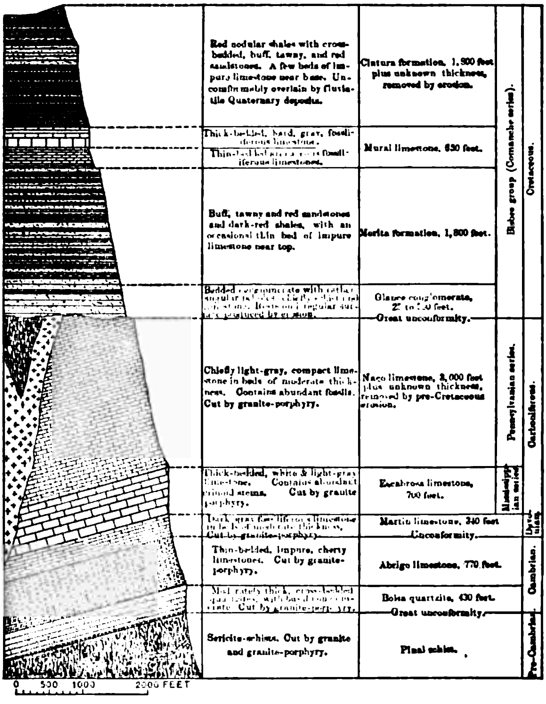


FIG. 156. — Geologic sections of Bisbee, Ariz., district. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 21.)

The Carboniferous limestone which carries the ore forms a shallow basin, which is cut through by the Dividend fault. The ore bodies, which are generally developed in the zone of metamorphic silicates surrounding the porphyry, as well as sometimes outside of it, form large, irregularly distributed, but rudely tabular masses, and mostly within 1000 feet of the granite-porphyry intrusion. No valuable ore bodies are found on the contacts. As now found the ore consists of malachite, azurite, cuprite, and other oxidized copper minerals above, which pass at variable depths into unaltered sulphides; but between the two, or at least never far from the effects of oxidation, masses of massive or sooty chalcocite are frequently found.

The primary ore consisted of pyrite, chalcopyrite, and occasionally sphalerite, and was deposited by a metasomatic replacement of the limestone. As originally formed, the deposits contained too little copper to make them commercially valuable, but they have been subsequently enriched by secondary replacement. In some places the ore is underlain by barren limestone, showing that secondary enrichment has extended to the very bottom of the ore body.

Disseminated pyritic ore is found in the porphyry of Sacramento Hill, but it has not proved workable.


Red nodular shales with cross-bedded, buff, tawny, and red sandstones. A few beds of impure limestone near base. Unconformably overlain by fluviatile Quaternary deposits.
Cintura formation, 1,900 feet plus unknown thickness, removed by erosion.
Thick-bedded, hard, gray, fossiliferous limestone.
Thin-bedded fossiliferous limestones.
Mural limestone, 650 feet.
Buff, tawny and red sandstones and dark-red shales, with an occasional thin bed of impure limestone near top.
Morita formation, 1,800 feet.
Bedded conglomerate with rather angular fragments chiefly of limestone. Rests on irregular surface produced by erosion.
Glance conglomerate, 2 to 500 feet.
Great unconformity.
Bisbee group (Comanche series).
Cretaceous.
Chiefly light-gray, compact limestone in beds of moderate thickness. Contains abundant fossils. Cut by granite-porphyry.
Naco limestone, 3,000 feet plus unknown thickness, removed by pre-Cretaceous erosion.
Pennsylvanian series.
Carboniferous.
Thick-bedded, white & light-gray limestone. Contains abundant crinoid stems. Cut by granite porphyry.
Escabrosa limestone, 700 feet.
Mississippian series.
Dark gray fossiliferous limestone in beds of moderate thickness. Cut by granite-porphyry.
Martin limestone, 340 feet
Unconformity.
Devonian.
Thin-bedded, impure, cherty limestones. Cut by granite-porphyry.
Abrigo limestone, 770 feet.
Moderately thick, cross-bedded quartzites, with basal conglomerate. Cut by granite-porphyry.
Bolsa quartzite, 430 feet.
Great unconformity.
Cambrian.
Sericite-schists. Cut by granite and granite-porphyry.
Pinal schist.
Pre-Cambrian.
0 500 1000 2000 FEET

GENERALIZED COLUMNAR SECTION OF THE ROCKS OF THE BISBEE QUADRANGLE.

Fig. 157. — Geological section at Bisbee, Ariz. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 21.)

The general relations of these ores to the intrusive porphyry and the contact silicates indicate that they are of contact-metamorphic origin.

In some cases an iron gossan has indicated an underlying ore body, but many others do not outcrop.

During 1908 the average copper content of the Bisbee ores was between 6 and 7 per cent. The gold and silver content per ton of refined copper was about $11 and $17 in two cases (Min. Res. U. S. Geol. Surv.).

Clifton-Morenci District (18). — The copper deposits of this district are located at Morenci (Fig. 155) and Metcalf in eastern Graham County. The ores were discovered in 1872, but remained undeveloped for a long time because of the fact that they were of too low grade, and too far from the railroads.

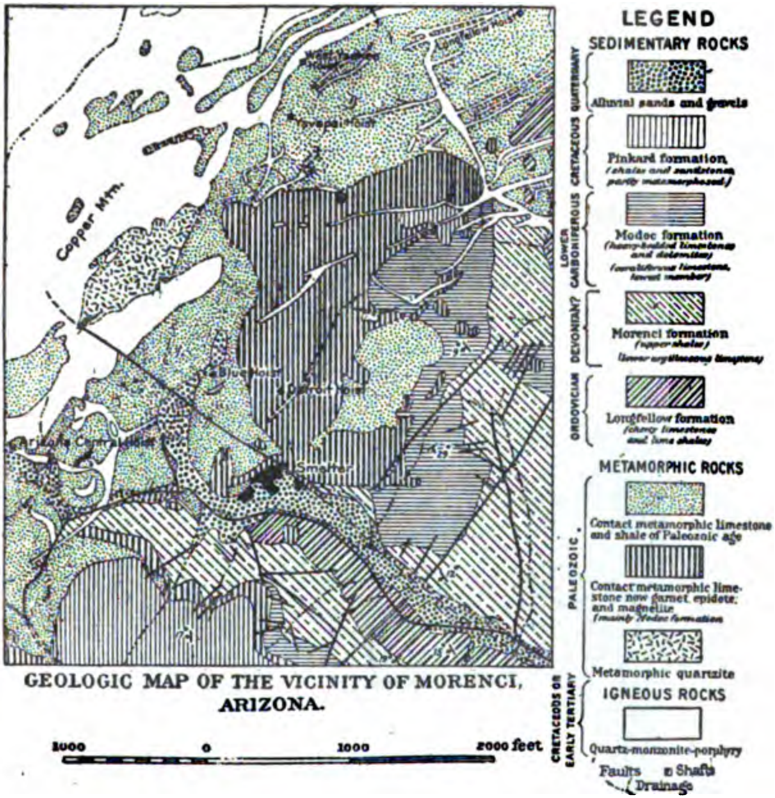

Copper Mtn.
Smelter
Longfellow
GEOLOGIC MAP OF THE VICINITY OF MORENCI, ARIZONA.
1000
0
1000
2000 feet
LEGEND
SEDIMENTARY ROCKS
QUATERNARY
Alluvial sands and gravels
CRETACEOUS
Pinkard formation
(shales and sandstones, partly metamorphosed)
LOWER CARBONIFEROUS
Modoc formation
(heavy-bedded limestones and dolomites)
(coralliferous limestone, lowest member)
DEVONIAN?
Morenci formation
(upper shales)
(lower argillaceous limestone)
ORDOVICIAN
Longfellow formation
(cherty limestones and lime shales)
METAMORPHIC ROCKS
PALEOZOIC
Contact metamorphic limestone and shale of Paleozoic age
Contact metamorphic limestone now garnet, epidote, and magnetite
(mainly Modoc formation)
Metamorphic quartzite
IGNEOUS ROCKS
CRETACEOUS OR EARLY TERTIARY
Quartz-monzonite-porphyry
Faults
Shafts
Drainage

FIG. 158. — Geologic map of vicinity of Morenci, Ariz. (*From Weed.*)

At the present time, however, these large bodies of low-grade ore are utilized, most of the work being done by three large companies.

The geologic section involves the following:
Quaternary (Gila) conglomerate.
Tertiary flows of basalt, rhyolites, and some andesites.
Cretaceous shales and sandstones. Several hundred feet thick.
Lower Carboniferous heavy-bedded pure limestones, 180 feet.
Devonian (?) shale and argillaceous limestone, 100 feet.
Ordovician limestone, 200 to 400 feet.
Cambrian (?) quartzitic sandstone, 200 feet.

Pre-Cambrian granite and quartzitic schists.

Intrusions of granitic and dioritic porphyries of post-Cretaceous age pierce all the older rocks, forming stocks, dikes, laccoliths, and sheets.

All of these rocks have been bowed up and subsequently faulted by late Cretaceous or early Tertiary movements.

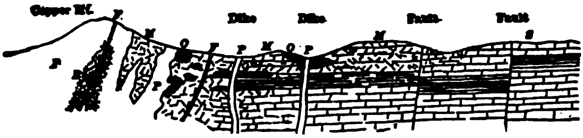


FIG. 159. — Section in Morenci, Ariz., district. *P*, porphyry; *S*, unaltered sediments; *F*, fissure veins; *M*, metamorphosed limestone and shale; *O*, contact-metamorphic ores; *R*, disseminated chalcocite. (*After Lindgren, Eng. and Min. Jour., LXXVIII.*)

Briefly stated, the distribution of the deposits of copper (Fig. 159) ore is practically coextensive with a great porphyry stock and its dike systems, the deposits occurring either in the porphyry or close to its contact, as well as along dikes of porphyry in some other rock.

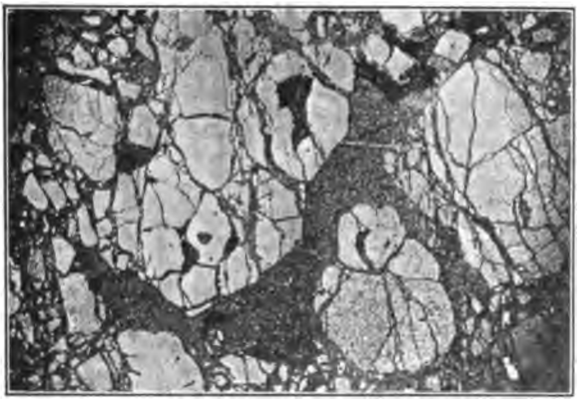


FIG. 160. — Photo-micrograph showing replacement in Clifton-Morenci ores. Dark gray chalcocite, developing by replacement of pyrite (light gray). The chalcocite is accompanied by small amounts of microcrystalline quartz, sericite shreds, and kaolin. Black areas represent open field. (*After Lindgren, U. S. Geol. Surv., Prof. Pap.* 43.)

The original ores were pyrite and chalcopyrite, of too low a grade to be workable, but they have since become so by a process of secondary enrichment. No ores were formed before the porphyry intrusion.

Where the latter is in contact with the granite and quartzite, but little change is produced, but where the porphyry is found adjoining the limestones or shales, extensive contact metamorphism developed, resulting in the formation of large masses of garnet and epidote, especially in the Lower Carboniferous limestones.

Where alteration has not masked the phenomena, magnetite, pyrite, chalcopyrite, and zinc blende accompany the contact minerals.

The ore bodies in the limestone are often irregular, but more frequently roughly tabular, because of the accumulation of the minerals along the stratification planes, or walls of dikes.

In many parts of the district the copper occurs in fissure veins which cut porphyry, granite, and sedimentary rocks, and were probably formed shortly after the consolidation of the porphyry. These in the lower levels carry pyrite, chalcopyrite, and sphalerite, but no magnetite. Surface leaching of these veins has often left limonite-stained, silicified porphyry outcrops.

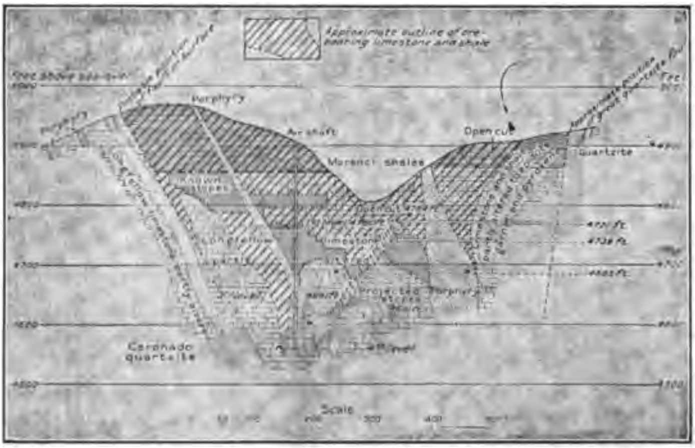


FIG. 161. — Vertical section through Longfellow ore body, Clifton-Morenci district. (*After Lindgren, U. S. Geol. Surv., Prof. Pap.* 43.)

Accompanying these veins, and of more importance commercially, are often extensive impregnations of the country rock. These disseminated deposits in the highly altered porphyry are leached out above, but lower down show a zone of pyrite and chalcocite, which does not usually extend below 400 feet.

Most of the copper in the district is obtained from concentrating ores containing chalcocite in altered porphyry. In 1908 the yield of copper from the concentrating ores was about 2.2 per cent, while the smelting ores yielded a little over 4 per cent.

The precious metal content is so low that much of the output of this district is not refined electrolytically unless the copper is not pure enough to put on the market.

The intrusions of porphyry produced strong contact metamorphism in the shales and limestones of Paleozoic age, resulting in the contemporaneous and metasomatic development of various contact silicates and sulphides,[1] the contact zone thus receiving large additions of iron, silica, sulphur, copper, and zinc, substances unknown in the sedimentary series away from the porphyry.

Subsequent to the solidification of the porphyry, extensive fissuring occurred in both it and sediments, resulting in the deposition of quartz, pyrite, chalcopyrite, and zinc blende in the fissures and by replacement of the wall rock. These are low in copper, but there is a close relation between the veins and contact deposits because of the similarity of their metallic contents, and of the similar development of tremolite and diopside where limestone forms the wall. The extensive impregnation of the porphyry also occurred at this time. Subsequent exposure of the deposits by erosion permitted the entrance of surface waters, which was followed by weathering and secondary enrichment.

Globe District (19). — The ore bodies here occur as lenticular replacements in limestone and fault lodes, or fissure zones in diabase.

Much of the limestone ore thus far extracted has been oxidized, but that in the diabase is enriched material. Some bodies of primary ore of commercial value have also been developed. About 70 per cent of the ore now treated is of the sulphide type, and in 1908 the ores yielded about 4½ per cent copper. The gold and silver contents are very low, averaging about .4 per cent per pound of copper.

Jerome District (17). — The ores, which are of pre-Cambrian age like the inclosing rock, consist of pyrite, chalcopyrite, some sphalerite, and varying amounts of quartz; replacing a schist that has been formed by the intense shearing of the basic porphyry. As a rule the more massive sulphide ore contains more iron and zinc, while the "slaty" ore, which consists of alternating bands of sulphide and schist, carries a higher proportion of chalcopyrite.

The ores mined are all of smelting grade, with a high percentage of copper, higher indeed than that of Bisbee, Bingham, Utah, Shasta County, California, and Ducktown, Tennessee. The gold and silver content is

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[1] Garnet, epidote diopside, etc., pyrite, magnetite, chalcopyrite, and sphalerite.

PLATE XXXIX

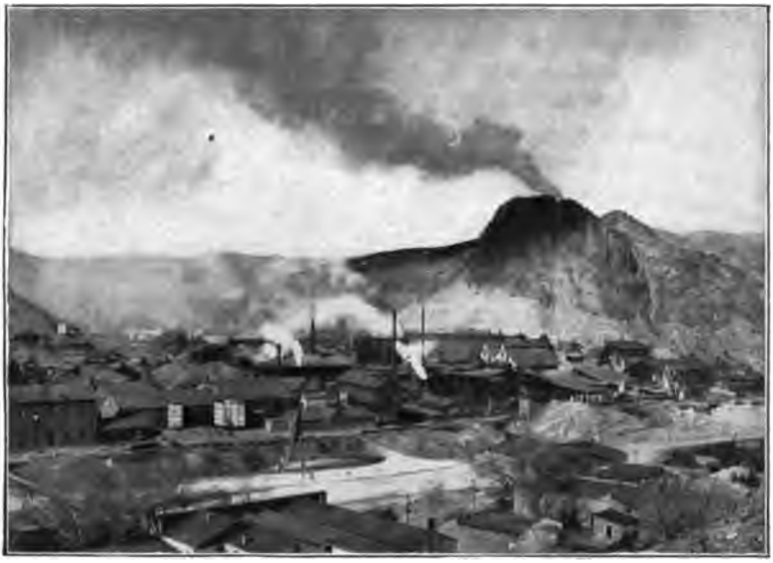

FIG. 1. — Smelter of Arizona Copper Company, Clifton, Ariz. (*After Church, Min. Mag., X.*)

FIG. 2. — View of Bingham Cañon, Utah. (*After Keith, U. S. Geol. Surv., Prof. Pap.* 38.)

also higher than that of any other of the large Arizona copper camps, and far above the pyrrhotite ores of Ducktown, Tennessee, but not much different from that of the Bingham and Shasta County ores.

Mineral Creek District (21). — This new district, which promises to be of some importance, is located in Pinal County (Fig. 155). The ore body consists of a great dissemination of chalcocite in schists (Fig. 162), and is said to average $2\frac{1}{2}$ per cent copper.

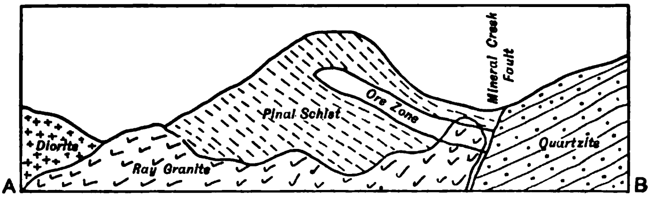

FIG. 162. — Vertical section (A B, Fig. 163) showing ore body in schist, Mineral Creek district, Arizona. (*After Tolman, Min. and Sci. Press, XCIX.*)

The schist, which is of pre-Cambrian age, forms a block which is faulted up against Paleozoic rocks on the east. Granite porphyry intrusions occur in the schist, quartzite, and diabase, and the first is strongly silicified near the fault.

This district is of interest because it represents a different mode of occurrence from that found in the leading Arizona ones.

Bingham Cañon, Utah (63). — This camp, which is the leading copper-producing locality of Utah, is situated in the north-central part of the state, on the eastern slope of the Oquirrh Mountains, 20 miles southwest of Salt Lake City.

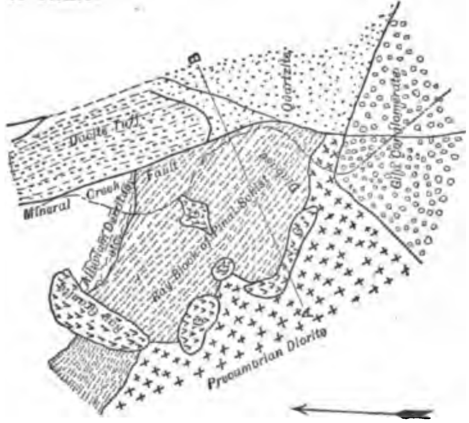

FIG. 163. — Geologic map of a portion of the Mineral Creek, Ariz., copper district. (*After Tolman, XCIX.*)

The rocks of this area include a great thickness of Carboniferous sedimentary formations, which are divisible into a lower member of massive quartzite with several interbedded limestones, and an upper member of quartzite with black calcareous shales, sandstones, and limestones.

The sediments, though showing in general a northerly dip, and northeast-southwest strike throughout the region, vary in their strike from east-west on the western slope to north-south on the eastern, so that they form a synclinal basin, with northward pitch.

The whole series of sediments, but especially the lower member, is pierced by an igneous intrusion, forming dikes, sills, and laccoliths. Prominent among these are two large areas of monzonite, one forming an irregular laccolith, the other a broad irregular stock. An extensive latite flow, outcropping on the eastern slope of the ranges, covered some of the sediments and older intrusives.

There has been fissuring at several different periods following the igneous intrusion, but in most cases displacement along these fractures does not exceed 150 feet. The northwest-southeast fissures carry the most important lead-silver ores.

The limestones of the lower member, averaging 200 feet in thickness, have been highly marbleized, and carry large bodies of copper ore, and the calcareous carbonaceous shales of the upper member sometimes carry it as well.

In many cases the ore is closely associated with the intrusives.

Two types of copper deposits are recognized, viz.: (1) great tabular replacement masses in limestone, lying roughly parallel with the bedding, and showing sometimes an extent of several hundred feet along the strike, as well as a thickness of even 200 feet; (2) disseminations in a large monzonite laccolith, especially in the fractured, fissured, and altered portions of the same.

The contact replacement deposits have been important ones in the past, but the enormous bodies of low-grade disseminated ore in the monzonite are now the most important (Pl. XL).

The limestone ores consist of primary pyrite and chalcopyrite, enriched in some cases by chalcocite and tetrahedrite. Quartz is the chief gangue mineral, but as might be expected in a contact deposit, garnet, epidote, tremolite, specularite, pyrrhotite, sphalerite, galena, etc., are also present.

The value of the ore is given by Weed as follows: copper content of replacement ores, 3.5 to 4 per cent, with gold \$.10 to \$1 and silver 2–5 ounces per ton.

The average content of the fissure ores is approximately 45 per cent lead, 65 ounces silver, and small amounts of gold, copper, and zinc.

Accessory gold, probably in pyrite, ranges in the copper, ores in limestone from \$.80 to \$2.20, in lode ores \$.50 to \$2.50, and in milling ores in monzonite about \$.30 per ton.

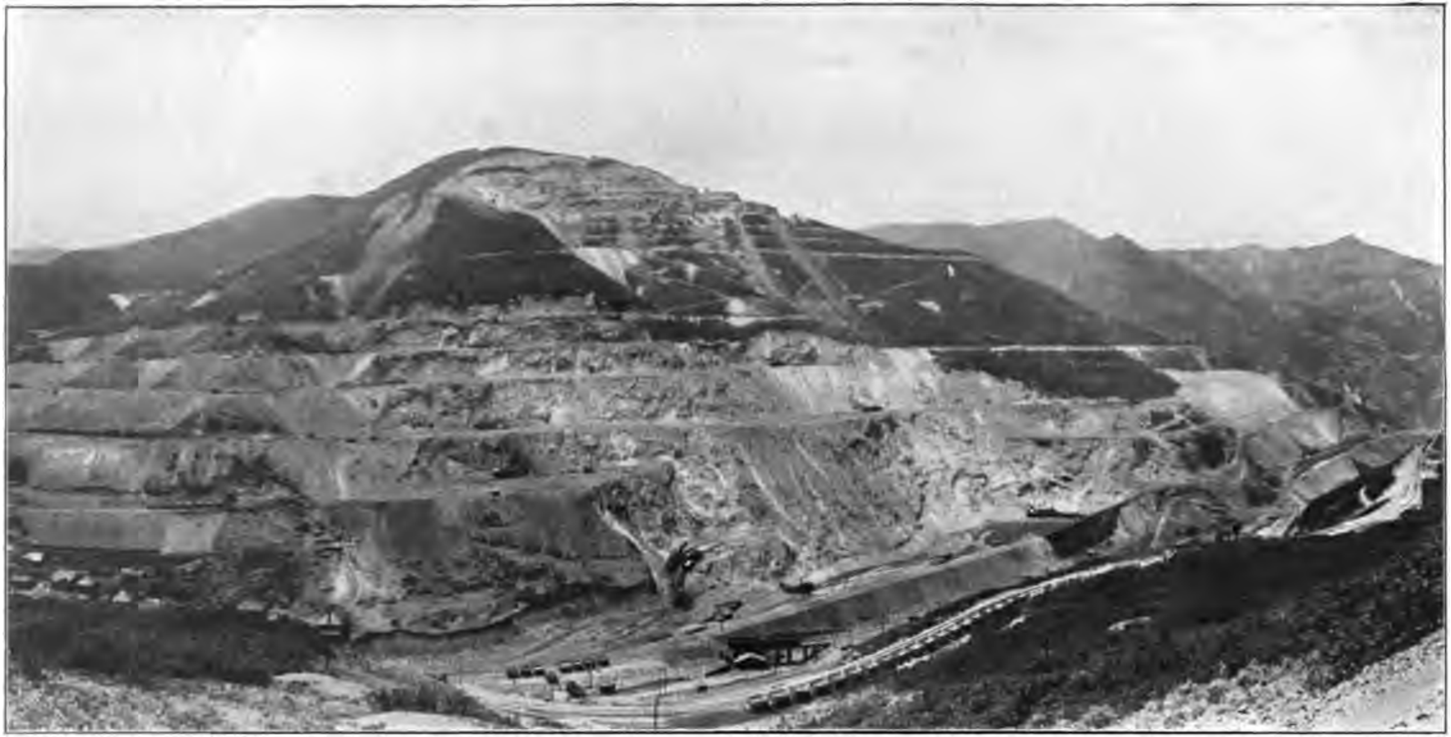

Plate XL. — Utah copper mine, Bingham, Utah. Showing great body of monzonite porphyry which is being worked for its copper contents. (Cut loaned by Amer. Inst. Min. Engrs.)

Zinc blende is a constant associate in the lode ores, and ranges from a trace to 45 per cent, averaging 10–15 per cent.

The Utah Copper Company gives as an average of a number of assays of its disseminated ores: copper, 1.98 per cent; gold, .016 ounces; and silver, .15 ounces per ton.

The theory of origin advanced by Boutwell is that the quartzites and limestones were intruded by the monzonite in Mesozoic or early Tertiary times, producing contact metamorphism of the limestone and replacing it with sulphides.

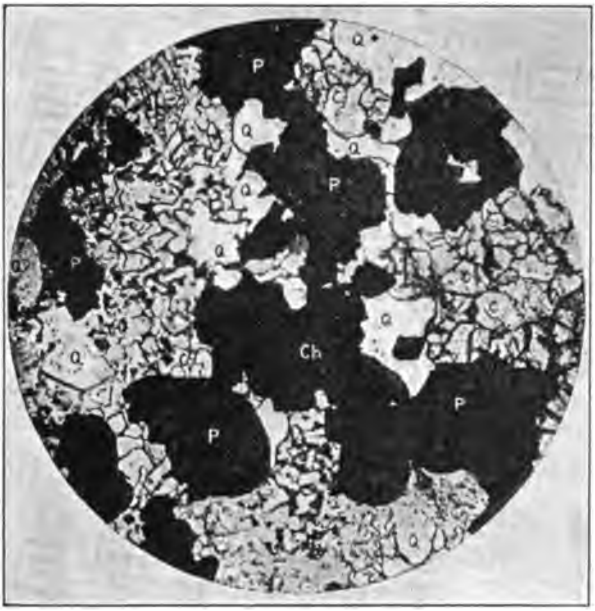

Fig. 164. Section showing replacement of limestone by pyrite (*P*) and chalcocite (*Ch*). Quartz (*Q*). (*After Boutwell, U. S. Geol. Surv., Prof. Pap.* 38.)

After the upper portion of the monzonite intrusion was partly cooled, the inclosing rocks were fractured by northwest-southeast fissures, along which there ascended heated aqueous solutions from the deeper, uncooled portions of the magma. These solutions not only altered the fissure walls, but deposited additional metallic sulphides, thus enriching the limestones as well as altering the monzonite by the addition of copper, gold, silver, pyrite, and molybdenite.

Ely, Nevada (51–53). — This district, although of recent development, promises to become of great importance. The copper belt, which lies 6 miles west of Ely, in White Pine County (Fig. 195), is about one mile wide and six miles long extending in an east-west direction.

It lies in a pass through the Egan Range, along what used to be a route to Eureka, Nevada.

The section there involves the following formations: —

Ruth limestone		
Arcturus limestone		1000 feet
Ely limestone, Carboniferous		1500 feet
White Pine shale	Devonian	1000 feet
Nevada limestone		1000 feet

The sediments which have a gentle dip are cut by a coarse-grained hornblende monzonite, which has effected only a limited amount of alteration in the adjacent limestone, producing some garnet rock and chalcopyrite.

There are present also dikes of porphyry and rhyolite lavas, the latter resting in the uneven limestone surface (Fig. 165), but these eruptives bear no genetic relation to the ore.

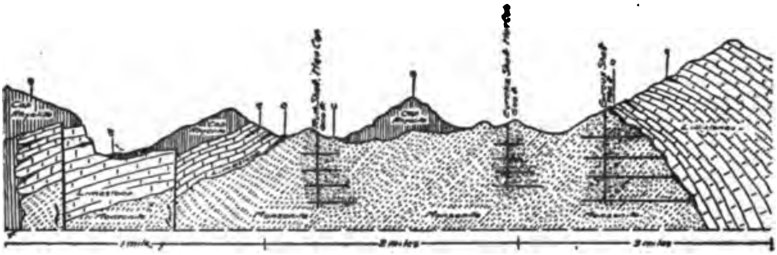

FIG. 165. — Section of Ely, Nev., district. (*From Weed.*)

Of importance in this connection are the monzonite intrusions, which carry ore. The ore, consisting of pyrite and chalcocite, is disseminated through the monzonite porphyry, but does not show on the yellowish and red weathered outcrop. In fact, there is a sharp line of separation between the gossan and unoxidized bluish white rock containing the grains of pyrite and chalcocite. The oxidized zone, which in the average extends to a depth of 100 to 150 feet, is very irregular and bears no relation to the ground water level.

Some of the ore bodies are of great size, that at the Ruth mine having a width of 50 to not less than 250 feet, and being developed for a length of not less than 900 feet.

Lawson believes that the ore bodies have resulted from a leaching of secondary ores in the oxidized zones and that the only primary

PLATE XLI

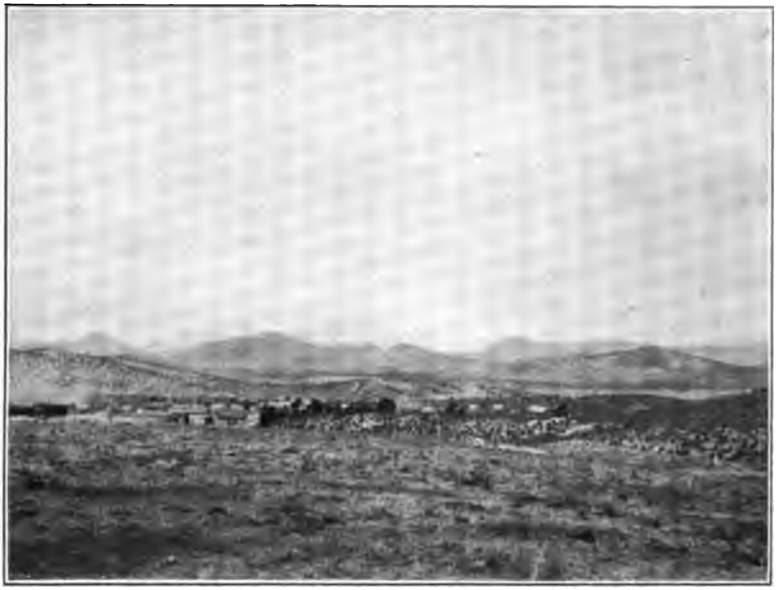

FIG. 1. — View looking northeast from the Eureka ore pit of the Nevada Consolidated Copper Company, Ruth, Ely district, Nev. (*D. Steel, photo.*)

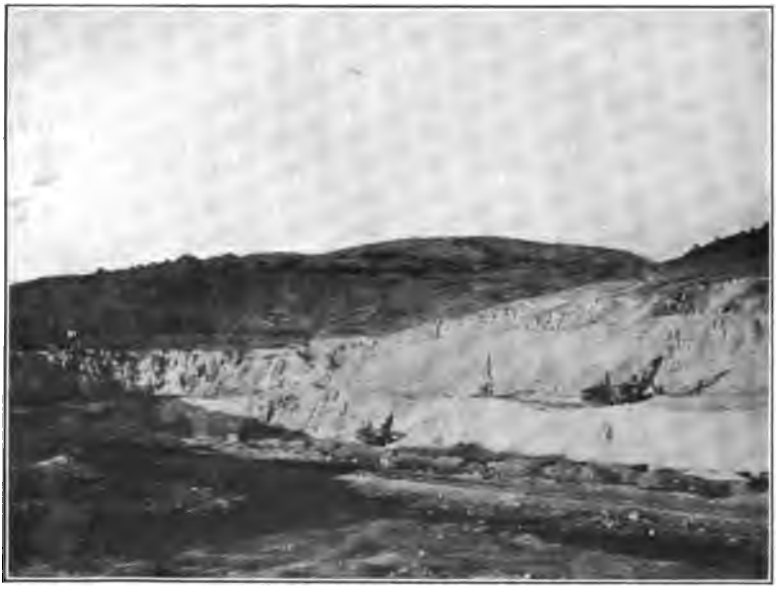

FIG. 2. — South end of the Eureka ore pit, Ruth, Nev. The hills in the background are limestone at the top and porphyry at the base. (*D. Steel, photo.*)

ore now known is the chalcopyrite in the garnet rock occurring beneath the quartz " blouts." These latter are masses of quartz occurring mainly along the contact, and formed by the replacement of both limestone and porphyry with silica which was leached out of the porphyry by carbonated waters.

The ores are of low grade similar to the disseminated ones at Bingham Cañon, Utah, and are worked in part as open cuts (Pl. XLI, Fig. 2). That from the Eureka Mine is said to average 2.2 per cent copper, with 40 cents gold per ton.

Appalachian States (32 *a*, 54, 55–59, 64–69). — The Appalachian states contain a number of deposits of copper ore distributed from Maine to Alabama, but few of them are of commercial importance. A number of different types are recognized occurring both in the Blue Ridge mountains and the Piedmont belt to the east.

The early attempts to work the deposits were chiefly to obtain both gold and copper, and resulted in failure, due largely to the low market values of copper; hence for many years the deposits, with few exceptions, have been but little worked, and it is only in recent years that a demand for the metal and cheaper metallurgical treatment have revived copper mining, at many localities, but not always with successful results.

Owing to the fact that the deposits usually occur in metamorphic rocks, their exact origin is somewhat in doubt.

Weed has suggested the five following types (5): —

1. True fissure veins, filled with quartz and copper, the vein crossing or conforming to the banding of the schists, and replacement of the wall rock being rare. The ores are bornite, with a little chalcopyrite and iron pyrite. The deposits at Virgilina, Virginia, belong in this group (69).

2. True fissure veins with auriferous quartz, chalcopyrite, and pyrite formed chiefly by replacement. The fissures are usually found along sheeting planes, and the deposits at Gold Hill, North Carolina, are taken as a type of this group.

3. Pyrrhotite veins of the Ducktown type (5), filling true fissures in mica schist, and consisting chiefly of pyrrhotite and pyrite with a little quartz. The ore has been formed by the replacement of a zone of sheeted rock, which was composed chiefly of metamorphic minerals, such as garnet, zoisite, actinolite, epidote, pyroxene, etc., these latter being the products of alteration of a calcareous shale. The Duckton ore body represents a type forming a belt extending all the way from Vermont to Alabama. They all show a gossan

which can be mined for iron ore, while under this there is a zone of black copper, the result of local enrichment, which passes into the sulphide ore below. The copper is richest in those portions where the pyrrhotite predominates.

In 1908 the ores of this district yielded 1.55 per cent copper, with an average of .38 per cent gold and silver per pound of copper electrolytically treated. The cheapness of operation of the mines and fuel make it possible to work this low-grade ore. The sulphur driven off in roasting the ore is utilized for sulphuric acid making, and the product can be marketed owing to the nearness of the phosphate rock supply which is used for fertilizer manufacture.

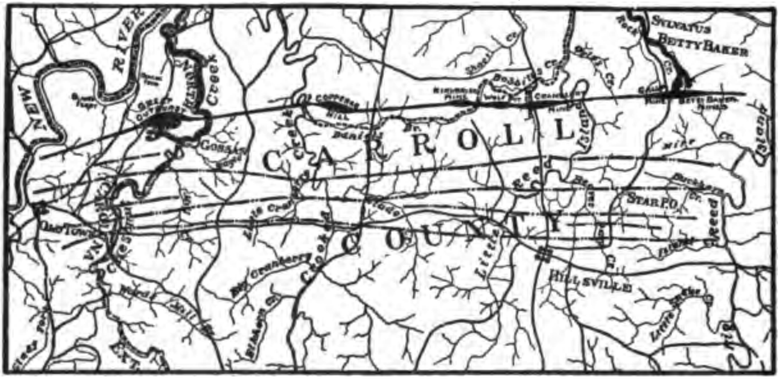

FIG. 166. — Map of Carroll County, Va., pyrrhotite area, showing position of the "Great Gossan Lead" in heavy black band, and principal copper mines located on it. Broken lines are other probable leads. (*After Watson and Weed, Min. Res. Va.*)

The Ducktown district was one of the earliest large producers in the United States, operations having begun in 1850, when the large supply of black copper ores were mined. The attempts to work the low-grade underlying sulphides were not successful until about 1890, since which time there has been a steady production.

The Gossan Lead of southwestern Virginia (68) (Fig. 166) and the copper deposits of Ore Knob, North Carolina, also belong to this type. At the former the ore is a mixture of pyrrhotite with subordinate chalcopyrite, and admixed quartz and schists. The vein fills a fault fracture between sericite schists, which contains mica, calcite, quartz, and actinolite, replaced by the later pyrrhotite and chalcopyrite (Fig. 167). The copper content is low, viz. .75

per cent, and hence the ore is used for acid making, but the residue is available for copper.

4. The Catoctin type, representing segregations of native copper, copper oxides, and carbonates along shear zones in altered igneous rocks of Algonkian age, the ores extending below ground-water level. They are found at a number of localities in the Appalachian and Piedmont plateau districts, usually in the Catoctin schist. The ore shows on the outcrop, but does not extend usually more than 50 to 60 feet below the surface. It is supposed to have been leached out of the vein walls. Occurrences of this type occur in Green County, Virginia.

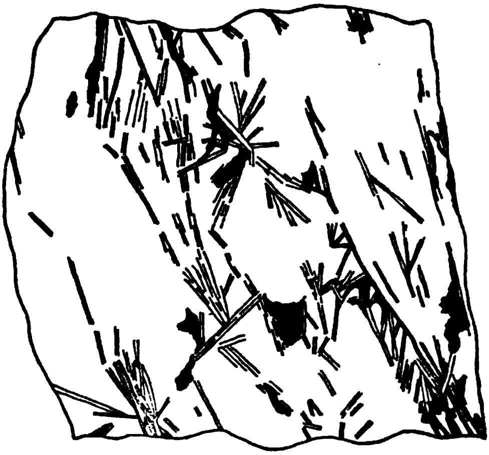

FIG. 167. — Section of ore from Chestnut Yard, Va., showing pyrrhotite (white) and chalcopyrite (black) replacements in hornblende (parallel lines). (*After Weed and Watson, Econ. Geol., I.*)

5. Deposits of native copper along the contact of diabase and sandstone. These have been found in New Jersey (54), but are unimportant, although the mines have been worked from time to time. Similar occurrences have been reported from Pennsylvania (55, 56) and Connecticut.

California (22–27). — Copper ores are mined in the Shasta County belt, north of Redding. The wall rock is mainly alaskite porphyry, which was probably intruded during Triassic times, and the ore bodies form replacements along zones of shearing. Those found in the western part of the region, and which include the Iron Mountain district, are somewhat tabular, while in the eastern part, including the Bully Hill district, the ore bodies are more veinlike in their character. In the western district the ore is pyrite with a small amount of chalcopyrite, while in the eastern sphalerite is of importance. The ores average about 3 per cent copper with $1.86 in gold and $.996 silver per ton. There are other scattered occurrences in the state.

Other Occurrences. — Colorado (28–32) has few copper mines proper, but many of the ores mined in the state carry copper, and it is utilized by lead smelters as a carrier in the extraction of other metals. Copper is mined in New Mexico and Idaho, the Seven Devils district (34) of the latter state being well known. The Grand Encampment district of southern Wyoming (24) has also supplied more or less ore, and a small amount is mined in Missouri (44, 45).

Alaska (6–13). — The four most promising and best-known copper regions of Alaska are (1) Ketchikan district on the Kasaan Peninsula and Hetta Inlet, the two being respectively on the east and west coast of Prince of Wales Island, (2) Prince Williams Sound district, (3) the region included within the drainage area of the Kotsina and Chitina rivers, and (4) the region of the upper Copper, Tanana, and White rivers. Three of these may be referred to.

Ketchikan District (12). — The most important ore bodies are contact-metamorphic ones occurring in irregular masses from 10 to 250 feet in dimensions, along the contacts of the intrusive rocks, usually with limestones, the ore composed mainly of chalcopyrite, magnetite, pyrrhotite, and pyrite in a gangue of amphibole, orthoclase, epidote, garnet, and calcite. In addition to these there are lode deposits in shear zones, vein deposits in fissures, and disseminated ores.

The ores mined are somewhat low in grade, with a little gold and silver, but high in iron and lime, and form a desirable flux for smelters of Tacoma and British Columbia.

At Copper Mountain in the Hetta Inlet district (Fig. 168) the ores are (1) contact deposits occurring between granite and limestone or schist, and (2) vein or shear zone deposits, occurring along the bedding planes of the greenstone schist and quartzites. The contact zone is of variable width and is broadest in the limestone.

Kotsina-Chitina Region (10). — This region, which is situated some distance from the coast, and hence difficult of access, has been but little developed, although transportation facilities have now been provided.

The ores are mainly sulphides associated with Triassic limestone and earlier greenstones. The ore is chiefly chalcocite, but other sulphides as well as oxidized ores occur. The most important deposit is the Bonanza mine on the Chitina River, which consists of a solid mass of chalcocite in limestone, averaging about 60 per cent copper, with about 22 ounces of silver to the ton.

Prince Williams Sound District (7, 8). — In this district the ore is chalcopyrite disseminated through metamorphic schists. The most important mine is on Latouche Island (9), and here the ore which is a mixture of chalcopyrite, pyrrhotite, and pyrite, has been deposited mainly as a cavity filling, less often as a replacement or impregnation, in a shear zone in interbedded slates and graywackes.

Uses of Copper. — Since prehistoric times copper alloyed with tin has been used in various parts of the world for the manufacture of bronze. Thus it was used for this purpose in Homeric times, and it is found in the lake dwellings of Switzerland. The bronze found in Troy contains a very little tin, and since this metal is not found in the excavations in the West, it seems probable that the bronze was made in Asia, perhaps in China or India, by some secret process, and imported to the western countries.

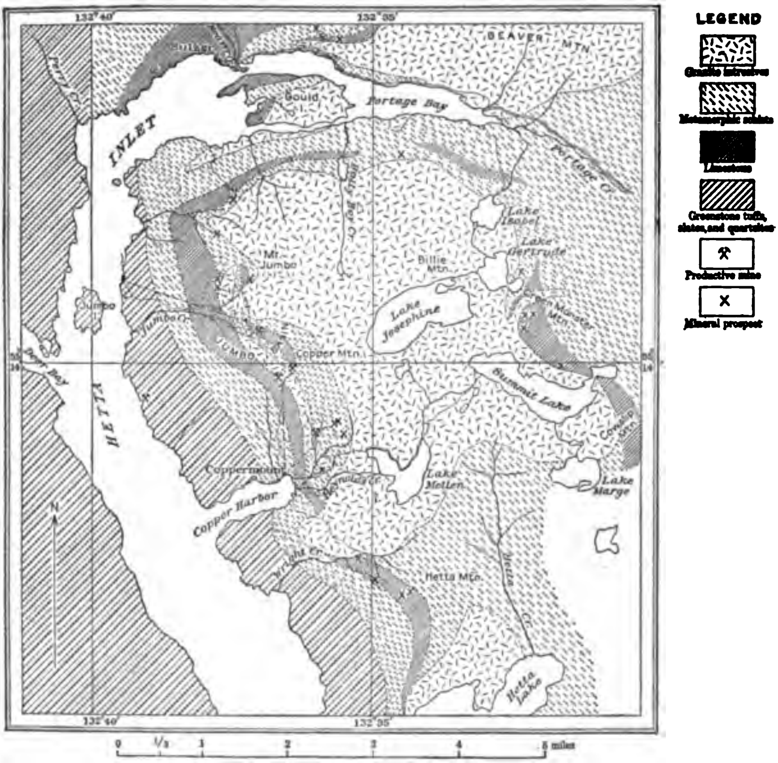

FIG. 168. — Geologic map of Copper Mountain Region, Prince of Wales Island, Alas. (*After Wright, U. S. Geol. Surv., Bull.* 379.)

By an alloy of copper and tin, although both metals are soft, a comparatively hard metal is produced. The properties of this alloy, bronze, vary greatly according to the proportions of the two metallic constituents, and these vary with the use for which the alloy is intended. United States ordnance is 90 per cent copper and 10 per cent tin, while ordinary bell metal is about 80 per cent copper, though the percentage varies with the tone required. Statuary bronze is generally an alloy of copper, tin, and zinc; and, in these various bronzes, the color varies from copper-red to tin-white, passing through an orange-yellow.

An alloy of copper and zinc produces brass, which is found of so much value for small articles used in building and for ornamental purposes in machinery. Copper is also used in roofing and plumbing.

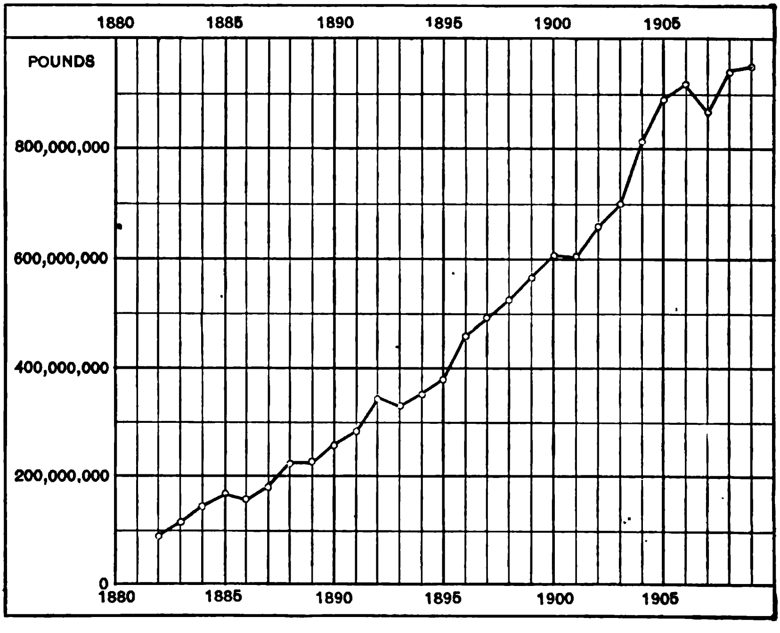

FIG. 169. — Chart showing production of copper in the United States, from 1882 to 1909. (*After Lindgren.*)

A large supply of this metal is made into copper wire, and the most important present use of copper is in electricity, for which its high conductivity especially fits it for the transmission of electric currents.

Production of Copper. — The production of copper in the United States has increased steadily and rapidly in the last fifty years, placing the United States in the lead of the world's copper producers. This increase can be seen from the chart (Fig. 169), and also in the following tables: —

Production of Copper in the United States, 1904–1908, by States, in Pounds

	1904	1905	1906	1907	1908
Arizona	191,602,958	226,854,461	262,566,103	256,778,437	289,523,267
Montana	298,314,804	314,750,582	294,701,252	224,263,789	252,503,651
Michigan	208,309,130	230,287,992	229,695,730	219,131,503	222,289,584
Utah	47,062,889	54,083,506	50,329,119	66,418,370	71,370,370
California	28,529,023	16,697,489	28,153,202	33,696,602	39,643,835
Colorado	9,506,944	9,404,830	7,427,253	13,998,496	13,943,878
Nevada	———	413,292	1,090,635	1,998,164	12,241,372
Idaho	2,158,858	7,321,585	8,578,046	9,707,299	7,256,086
New Mexico	5,368,666	5,334,192	7,099,842	10,140,140	4,991,351
Alaska	2,043,586	4,900,866	8,665,646	7,034,763	4,438,836
Wyoming	3,565,629	2,530,531	106,177	3,026,004	2,416,197

World's Production (Smelter Output) of Copper in 1908 in Pounds

Country	1908	Country	1908
Algeria	none	Mexico	84,156,800
Argentina	504,000	Namaqualand	none
Australasia	88,480,000	Newfoundland	3,203,200
Austria	3,528,000	Norway	20,585,600
Bolivia	5,600,000	Peru	33,600,000
Canada	63,996,800	Russia	44,990,400
Cape Colony	15,411,200	Spain	117,790,400
Chile	85,825,600	Portugal	
England	1,568,000	Sweden	4,480,000
Germany	45,248,000	Turkey	2,352,000
Hungary	224,000	United States	942,570,000
Italy	6,664,000		
Japan	96,320,000	Total	1,667,098,000

Total Imports and Exports of Copper including Ore, Matte and Regulus, Pigs, Bars, Ingots, and Plates

	Imports Pounds	Exports Pounds
1907	252,620,054	731,005,241
1908	218,705,487	803,329,887

Copper Reserves. — Lindgren (5 *a*) points out that the visible copper reserves of the United States are much larger than those of lead ore, and, moreover, they are much larger, now, at the maximum of production, than they have ever been before, and yet they are in most cases not nearly so great as those blocked out for some other materials like coal. This, however, is owing to the different mode of occurrence of the two substances. The amount of available reserves to be estimated depends on the market price of copper. With the latter at, say, 20 cents per pound one can estimate a much larger reserve than if the price were only 13 cents. Lindgren believes that the copper resources of the United States are large enough to respond for a number of years to a demand increasing at the rate of 30,000,000 pounds per annum.

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CHAPTER XVII

LEAD AND ZINC

It is usually customary to treat these two ores together for the reason that they are so frequently associated with each other, but it must not be understood from this that they are found free from association with other metals, as in the Rocky Mountain region, for example, gold, silver, or copper may often occur with them, forming ores of somewhat complex character.

The silver-lead ores form a somewhat distinct class and are treated separately.

Ore Minerals of Zinc.—The zinc-ore minerals, together with the percentage of zinc which they contain, are:—

Sphalerite (Isometric) .	ZnS	67
Wurtzite (Hexagonal) .	ZnS	67
Smithsonite	$ZnCO_3$	51.96
Calamine	$2ZnO,SiO_2,H_2O$	54.2
Hydrozincite	$ZnCO_3,2Zn(OH)_2$	60
Zincite	ZnO	80.3
Willemite	$2ZnO,SiO_2$	58.5
Franklinite	$(FeMnZn)O,(FeMn)_2O_3$	variable

Of these ores, sphalerite (also known as blende, jack, rosin jack, or black jack) is by far the most important, except in northern New Jersey, where it is practically lacking and franklinite and willemite abound.

Sphalerite may be either a primary or secondary ore. Wurzite has been noted in some of the Missouri ores, and many massive blendes may be a mixture of sphalerite and wurtzite.[1]

Blende is often associated with other sulphides, especially galena, pyrite, and marcasite, but more rarely chalcopyrite.

Smithsonite, found in the oxidized zone, is a comparatively rare ore mineral in the United States, although it is an important one in Europe. Calamine, also an oxidized ore mineral, is far more abundant, and found in many deposits. Both smithsonite and calamine may occur in a pure and crystalline form, but more often they are quite impure, and of crusted or earthy character. Hydrozincite is not uncommon in some districts.

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[1] J. Noelting, Zeit. Kryst. u. Min., XVII : 220, 1890.

Ore Minerals of Lead. — The lead-ore minerals, together with their composition and the percentage of lead which they contain, are: —

Galena	PbS	86.4
Cerussite	$PbCO_3$	77.5
Anglesite	$PbSO_4$	68.3
Pyromorphite	$Pb_3P_2O_8 + \frac{1}{3} PbCl_2$	76.36

There are a vast number of lead minerals in addition to the above, but they have little or no commercial value on account of their rarity.

Of the above-named ore minerals galena is the commonest, and may be of either primary or secondary character. It frequently, especially in the complex ores, carries variable amounts of silver. The other three lead-ore minerals are usually found in the oxidized zones, and the cerussite is not uncommon, but the sulphate when formed usually changes to the carbonate.

The lead and zinc ores may be divided into three groups as follows: (1) lead and zinc ores, practically free from copper and the precious metals; (2) lead and zinc ores, carrying more or less gold and silver, as well as some iron and copper; (3) lead-silver ores.

In the first group iron, lead, and manganese are not uncommon impurities, and those of southwestern Missouri contain small amounts of cadmium; but this is not injurious, as it is more volatile than the zinc and easily driven off. Calcite, dolomite, and pyrite or marcasite are common gangue minerals, and barite or fluorite may occur at certain localities.

The ores of the second group are confined to the Rocky Mountain region, and are not only of complex character, but differ in their form and origin from most of the eastern ones. Quartz is probably the commonest gangue mineral, but there may be other less important ones. Antimony, arsenic, and iron may be among the impurities.

The silver-lead ores, which are confined to the western states, carry silver and lead as their chief metals, but may contain smaller amounts of zinc, gold, or iron. They show a preference for limestone.

Mode of Occurrence. — Zinc and lead ores may occur under a variety of conditions, viz.: (1) as true metalliferous veins; (2) irregular masses in metamorphic rocks; (3) as irregular masses or disseminations, formed by replacement or impregnation in limestones or quartzites; (4) in contact-metamorphic deposits; (5) in cavities not of the fissure-vein type; and (6) in residual clays.

Both lead and zinc are what may be termed somewhat persistent minerals, since they are able to form under a variety of physical conditions, originating[1] in contact deposits, deeper vein zones, middle and upper vein zones, and by the action of meteoric waters. It will be noticed, from the foregoing, that none occur as magmatic segregations.

Neither lead or zinc ores are restricted to any one formation, but the majority of economically valuable deposits of these metals, without silver, gold, or copper, are found in the Paleozoic formations, although a few are known in pre-Cambrian rocks.

While the metallic content of the ore as mined is often low, still, owing to the great difference in gravity between ore and gangue minerals (excepting pyrite or marcasite and blende), it is often possible to separate them by mechanical concentration; and for the zinc ores magnetic separation has been successfully tried.

Superficial Alteration of Lead and Zinc Ores. — Galena is often altered near the surface to anglesite or cerussite. The former, however, is unstable in the presence of carbonated waters and changes readily to carbonate. Phosphates are developed in rare instances.

Sphalerite, the common ore of zinc, is often changed superficially to smithsonite, hydrozincite, or calamine. Such oxidized ores are of greater value than unoxidized ones, because, although carrying a lower percentage of zinc, they occur in a more concentrated form and yield more easily to metallurgical treatment.

The sulphates and carbonates produced by weathering may be carried down below water level and reprecipitated as sulphides, thus causing secondary enrichment.

Some of the reactions which may take place are referred to under secondary enrichment in Chapter XIV.

Owing to the fact that sphalerite weathers more rapidly than galena, the zinc is usually carried down below water level more rapidly than the lead, and this may result in a zonal distribution of the ore, lead predominating above and zinc below. Cases of this sort are not uncommon.

Distribution of Lead and Zinc Ores in the United States (Fig. 170). — The occurrence of lead or zinc with gold, silver, and copper is confined chiefly to the Cordilleran region, and shows a most varied mode of occurrence; but commercially valuable deposits of lead alone, or lead and zinc, are confined to the Mississippi Valley, while those of zinc alone or with little lead are restricted to the Appalachian region as seen below.

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[1] Lindgren, Econ. Geol., II: 107.

Lead Alone. *Appalachian Belt* (17, 34). — Lead (sometimes argentiferous) occurs at a number of localities from Maine to Georgia filling small veins in metamorphic rocks, and the deposits have at various times aroused temporary interest. There is no likelihood of their ever becoming important producers, although exciting rumors regarding them are occasionally circulated.

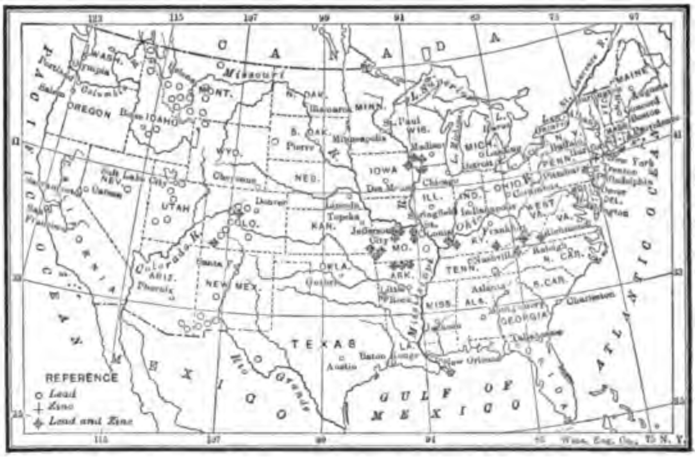

FIG. 170. — Map showing distribution of lead and zinc ores in the United States. (*Adapted from Ransome, Min. Mag., X.*)

Southeastern Missouri[1] (22, 26). — The disseminated lead ores of southeastern Missouri lie mainly within St. Francis, Washington, and Madison counties, the geologic section involving the following formations: —

Upper and Middle Cambrian.	Potosi dolomite.	300 ft. +
	Doerun argillaceous dolomite.	60–100 ft.
	Derby dolomite, thickly bedded.	40 ft.
	Davis formation, chiefly shale with thin beds of limestone, dolomite and limestone conglomerate.	170 ft.
	Bonneterre, mainly magnesian limestone with sandy dolomite and shale.	365 ft. ±
	Lamotte sandstone.	200 ft. or less.
	Unconformity.	
Pre-Cambrian.	Granite and rhyolite with intrusive diabase dikes.	

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[1] The abstract of this district was kindly furnished by Dr. E. R. Buckley.

While the sedimentary series as a whole has retained its originally approximately horizontal position, there are numerous local dips, some of which may be as much as 45°. The numerous small faults of the district are roughly groupable into a northeast-southwest and a northwest-southeast system. Most of the faults are of normal type and usually have a throw of less than 100 feet; but those of the major zones show aggregate displacements of 700, 600, and 400 feet respectively.

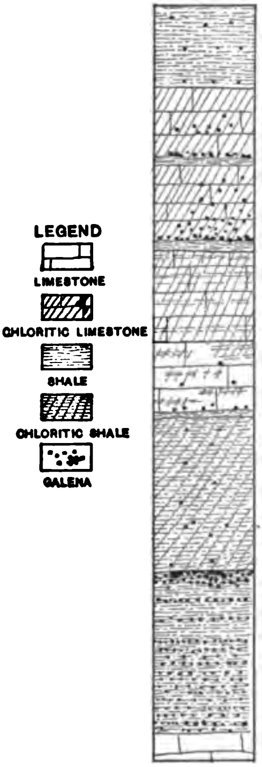

FIG. 171. — Four and one half foot section showing occurrence of ore in Bonneterre limestone, Doe Run, Mo. (*After Buckley, Mo. Bur. Geol. Min., IX.*)

The ore bodies of the district usually lie in pitching troughs, and while some galena of massive crystallized type has been mined with profit from the Potosi, and upper part of the Bonneterre, the disseminated deposits, which are the main source of the lead ore in the district at the present day, occur mainly in the lower half of the Bonneterre.

In the so-called disseminated lead-ore bodies, seven types of occurrence are noted, of which the first is the most important: (1) disseminations in dolomite, shale, and chloritic rock; (2) horizontal sheets along bedding planes; (3) filling or lining the walls of joints; (4) in cavities, vugs, and similar openings, sometimes embedded in soft blue clay or mixed with calcite and pyrite; (5) in shale along fault planes; (6) in cubes and aggregates of cubes in red clay, filling channels and large openings along fault zones; (7) as cerussite in decomposed dolomite.

The disseminated lead-ore bodies are in part the result of the abstraction of lead from waters circulating along channels and bedding planes in their journey from the surface to the Lamotte sandstone, and in part from solutions, under hydrostatic pressure, which rise along channels extending upward into the dolomite, from the underlying sandstone.

In the Bonneterre formation the conditions were favorable for the reduction of the metallic salts, resulting in their precipitation as ore bodies.

The details of the deposition are considered to be about as follows: At the surface there is an oxidized zone containing galena, which is being abstracted by surface water percolating down towards the Lamotte sandstone, which on account of its high porosity serves as a storage reservoir of water containing lead in solution. Between these two zones is the Bonneterre formation, with its carbonaceous and chloritic reducing agents, and in which formation the lead has been deposited.

Channels furnish connecting ways between the oxidized zone and the sandstone, and the rocks along these have been and are being oxidized, permitting the direct transference of oxidizing solutions, carrying lead.

Some water may have also entered the sandstone by other channels.

The dolomite, which is now oxidized along the channels traversing it, was at one time of a reducing nature, and the deposition of the galena found in the rock adjacent to these passageways must have occurred before the dolomite was oxidized. At such time any oxidizing solutions carrying lead which penetrated the lower horizon of the Bonneterre formation must have been brought in from other areas, chiefly through the rock outcropping near the area of igneous rocks. The galena in the crevices may have been introduced in part by ground water from the surface, and in part from water rising from the Lamotte sandstone. It is thought that the ore bodies in the Bonneterre are mainly subsequent to the establishment of zones of communication along the oxidized channels. The original source of the lead was the igneous rocks, its transference to the sedimentary formation having taken place during successive periods of decomposition by the surface and ground water circulations, the waters carrying the metallic compounds down into the sea where they became incorporated in the sediments then forming.

Desilverized Lead.[1]—The important localities supplying this type of lead are described under lead-silver ores, but brief reference may be made to them here. Idaho is the most important producer, most of the ore coming from the Cœur d'Alene district. In Utah much is obtained from the Park City district of Summit County, the Bingham Cañon and Cottonwood districts of Salt Lake County, and the Tintic district of Juab County. Colorado's main supply is yielded by the Leadville mines in Lake County and the Aspen mines of Pitkin County, while smaller amounts are abtained from Creede, Lake City, Ouray, and Rico. (See Lead-Silver references.)

Comparatively little lead is produced in the western states, except in the three mentioned above.

As pointed out by Bain, the important lead ores of this region are closely associated with both igneous and sedimentary rocks. At

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[1] This term is applied to those occurrences of lead associated with silver. In the smelting of the ore, the two metals are separated.

Leadville, Aspen, and Park City the sediments are dolomites and limestones, and at Cœur d'Alene they are shales and quartzites. While the ores seem to favor igneous associations, still the larger bodies are found where both classes of rocks occur.

Zinc Ores. — The zinc-producing regions of the United States are the eastern and southern states, the Mississippi Valley, and the Rocky Mountain region.

The ore from the different districts varies in grade, associations, and mode of occurrence.

In tonnage terms, the main zinc-producing districts are the Joplin, Missouri, Sussex County, New Jersey, and Colorado. The Joplin ores are the main source of supply of the Kansas, Missouri, and Illinois smelters, but Colorado and even British Columbia ore is shipped to Kansas. Most of the New Jersey ore is used for zinc oxide, but smaller amounts are exported or used for spelter.

Eastern and Southern States. — The localities where zinc alone occurs are Sussex County, New Jersey; Saucon Valley, Pennsylvania; and the Virginia-Tennessee belt. Of these the first is the most important, and the third yields a little lead.

Sussex County, New Jersey (27–29). — The output of these mines is second in importance to those of the Mississippi Valley region. The district (Pl. XLII) includes two general areas situated close together, the one called Mine Hill, at Franklin, and the other called Sterling Hill, at Ogdensburg, two miles farther south.

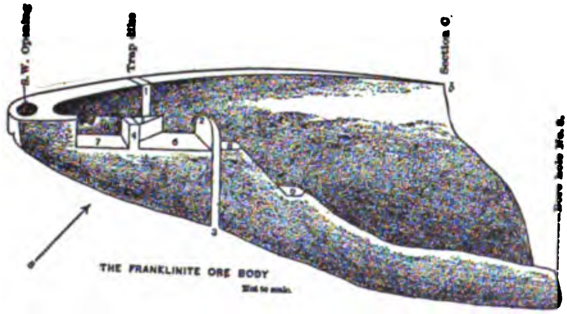

FIG. 172. — Model of Franklin zinc-ore body. (*After Nason, Amer. Inst. Min. Engrs., Trans. XXIV.*)

The ore deposits are in white limestone, which is bounded on the northwest by gneiss, and on the southeast by blue Cambrian limestone along a fault line.

At Mine Hill (Fig. 172) the northerly pitching ore body lies in the white limestone adjacent to its contact with the gneiss, and has the shape of a trough, whose southern end appears to be doubled over into an anticline. Magnetite deposits outcrop locally along the

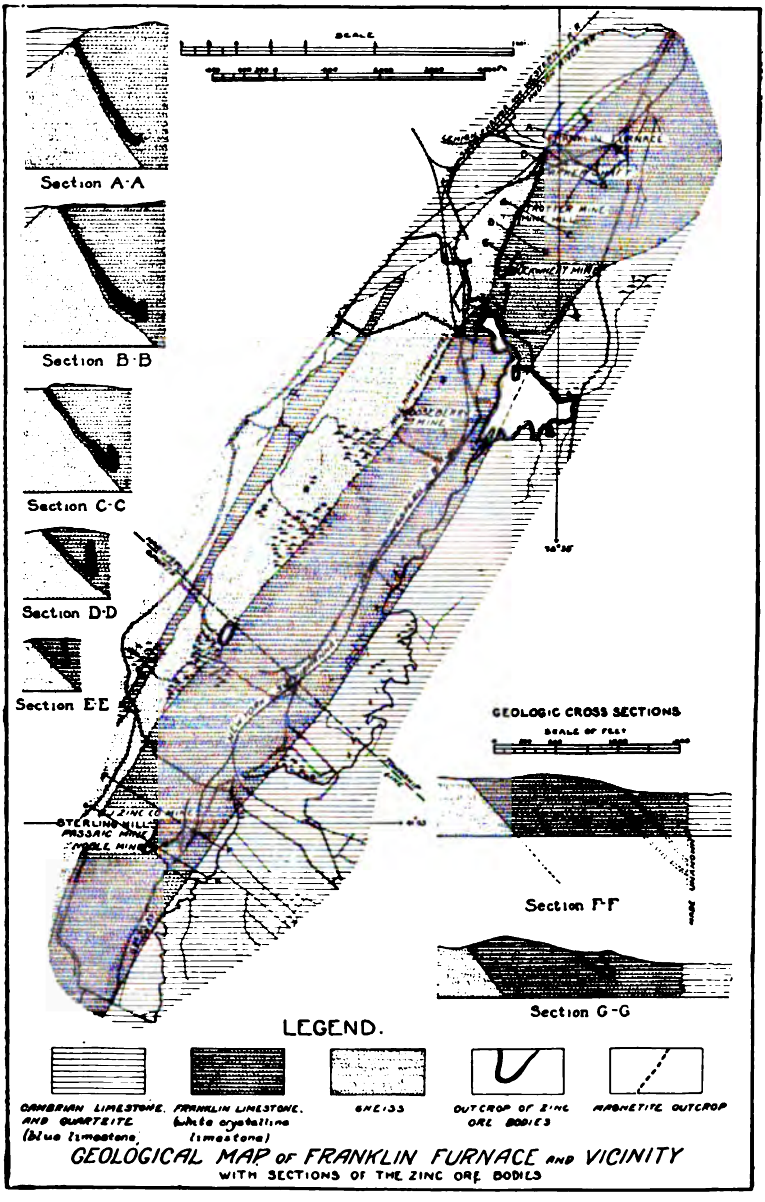

Plate XLII.—Geologic map of Franklin Furnace and vicinity, with sections of the zinc-ore bodies. (*After Spencer, N. J. Geol. Surv.*)

limestone gneiss contact, both adjacent to the zinc deposit, and for a distance of more than one half mile to the southwest.

The Sterling Hill (Fig. 173) deposit at Ogdensburg lies away from the limestone gneiss contact. The ore body is also a trough, which pitches towards the east, and has a hook-like outcrop. Both sides of the trough dip southeast; the exact extent of this ore body is not known.

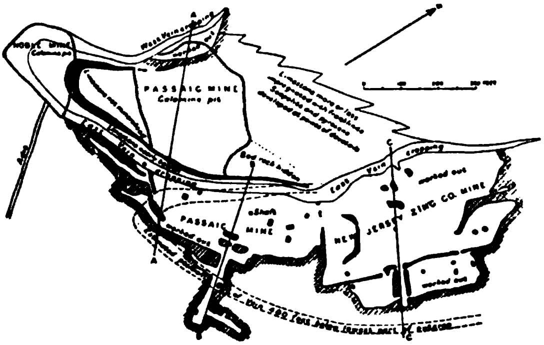

FIG. 173. — Plan of outcrop and workings of the Sterling Hill ore body. (*After Spencer, N. J. Geol. Surv., Ann. Rept.*, 1908.)

The ore minerals are principally franklinite, willemite (often somewhat manganiferous), and zincite. These, together with tephroite, are practically the only metallic minerals at Sterling Hill; but in the Mine Hill deposits, several other zinc- and manganese-bearing minerals, mainly silicates, are not uncommon. Sphalerite occurs sparingly.

The gangue minerals are calcite, rhodonite, garnet, pyroxene, and hornblende. The ore is granular, and some of it shows strong foliation. There is usually a gradation from ore into country rock, and while the ore appears to show a lamination corresponding with that of the gneisses, the three dominant ore minerals mentioned are not evenly mixed in all parts of the ore body.

At Mine Hill the run of mine ore has been estimated to contain from 19 to 22.5 per cent iron, 6 to 12 per cent manganese, 27 per cent zinc.

The franklinite has been found to contain from 39 to 47 per cent iron, 10 to 19 per cent manganese, and 6 to 18 per cent zinc; the willemite from 1.5 to 3 per cent each of iron and manganese; and the zincite about 5 per cent manganese and iron.

At Sterling Hill the limestone lying between the outcropping ends of the sides of the trough is mineralized, while inside the trough of ore there is a curved dike of hornblendic pegmatite, and on the convex side of the dike, towards the ore, there are occasional developments of garnet, zinciferous pyroxene, and biotite.

We have in this district two zinc deposits, which are quite different from all other known deposits of this metal, not only because of the association of iron, manganese, and zinc in such ore bodies, but also because of the form of combination of the zinc ores. Thus we have the oxides franklinite and zincite, together with the silicate willemite, occurring in great abundance, although very rare elsewhere.

The origin of these deposits is of unusual interest, for they not only contain in abundance a number of zinc minerals, rare or unknown elsewhere, but many other mineral species as well.

Kemp (27) considers that the ore was probably deposited by solutions stimulated by intrusions of granite, and subsequently metamorphosed, but Wolff (29) suggests that they are contemporaneous in form and structure with the inclosing limestones and hence older than the granites.

Spencer (28) argues that the present characters of the ore masses and wall rocks originated contemporaneously because the two are not sharply separated; so that the deposits must have been introduced either before or during the metamorphism of the containing rocks and the igneous rocks which are now gneisses. He favors the view that the lean ore of Sterling Hill was probably deposited by magmatic waters which permeated and replaced the limestone, and while the richer ore may have been formed in the same way, there is also the possibility that the main ore layer at Sterling Hill and the mass of ore at Mine Hill were injected bodily into the limestones, like igneous intrusions.

The pegmatites are evidently the source of many of the rarer minerals found in these deposits, because they are closely associated with them.

But after all the work that has been done in studying these deposits, one has to admit, without any intention to disparage the investigators, that the theories regarding the possible origin of these deposits are still largely speculative

These ore bodies are of some historic interest, having been prospected as early as 1640 and mined in 1774. The Mine Hill deposits were worked for iron ore as early as the beginning of the last century, the zinc mining having begun about 1840.

The Sussex County ores, while chiefly valuable as a source of zinc, are likewise of importance because of their iron and manganese contents.

Three products. viz. spelter, zinc oxide, and spiegeleisen, are made from them.

The Mine Hill ores are now treated by magnetic separators, which yield three products, as follows: 1. Mainly franklinite, used in preparation of zinc white, the residuum from this going to blast furnace to make spiegeleisen. 2. Half and half, containing franklinite, rhodonite, garnet, and other silicates with attached particles of the richer zinc minerals. This contains a little more zinc than the franklinite, and while it can be used for zinc white, the residuum is too high in silica for the spiegeleisen furnaces. 3. Willemite product, which consists of willemite and zincite, with calcite and silicates as impurities. The calcite is removed in jigs and on concentrating tables, leaving material adapted to manufacture of high-grade spelter free from lead or cadmium.

The dust from the crushing and concentrating plant is also saved for making zinc oxide. The following gives the approximate percentage of each product and its zinc contents.

Products of Mill at Franklin Furnace

	Per Cent of Each	Per Cent of Zinc
Franklinite	49	22
Half and Half	12	24
Dust	4	27
Willemite	25	48
Calcite	10	5
	100	

Virginia-Tennessee Belt (39, 40, 47). — Zinc and some lead occur in a belt extending from southwest Virginia into Tennessee. The ores are intimately associated with Cambro-Ordovician limestone, and show two types, viz.: (1) secondary or weathered ores, including calamine, smithsonite, and cerussite, which are concentrated in the residual clays next to the irregular weathered surface of the limestone (Fig. 174); and (2) primary ores, including sphalerite, galena, and some pyrite, belonging to the disseminated replacement breccia

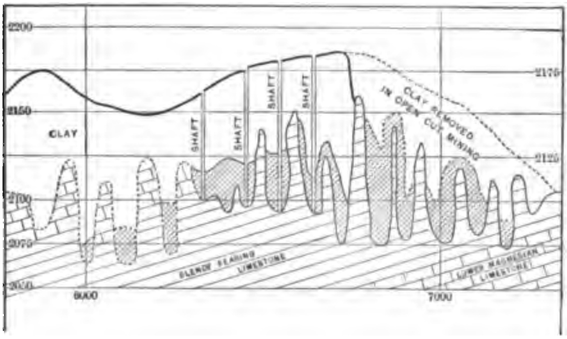

Fig. 174. — Section of Bertha zinc mines, Wythe Co., Va., showing irregular surface of limestone covered by residual clay-bearing ore. (*After Case, Amer. Inst. Min. Engrs., Trans. XXII.*)

type (Fig. 175), and which have been localized by ground waters along the crushed and faulted axes of the folds. The gangue minerals are chiefly calcite, dolomite, and some barite. Fluorite is known, and quartz may occur in the form of chert. One deposit only, in Albemarle County, is found in schist, and is closely associated with igneous rocks.

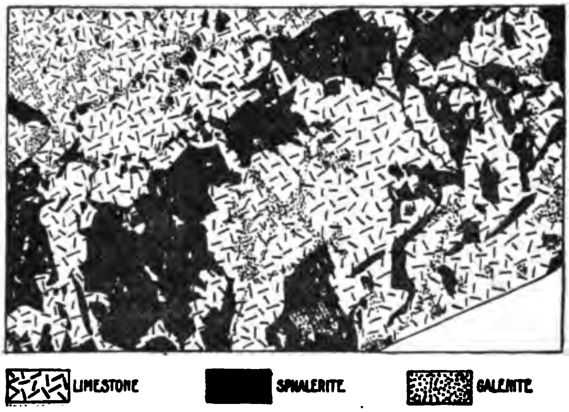

FIG. 175. — Section showing replacement of limestone by sphalerite and galena, Austinville, Va. (*After Watson, Va. Geol. Surv., Bull. I*, 1905.)

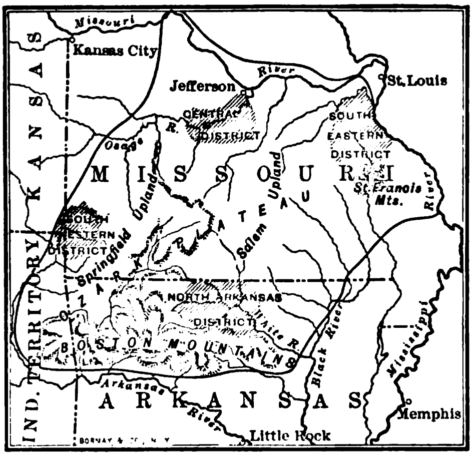

FIG. 176. — Map of Ozark region. (*After Branner, Eng. and Min. Jour., LXXIII.*)

Pennsylvania (37, 38). — The Saucon Valley deposits promised at one time to become prominent producers, but have not, owing more to geological conditions than actual scarcity of ore.

Mississippi Valley Lead and Zinc Region. — This region contains several somewhat separated groups of deposits, viz.: (1) the Ozark Region, (2) upper Mississippi Valley area, (3) outlying districts, chiefly in southern Arkansas, and Kentucky and Illinois. Of these the first is the most important.

Ozark Region (18-26). — This region, which lies mostly in Missouri

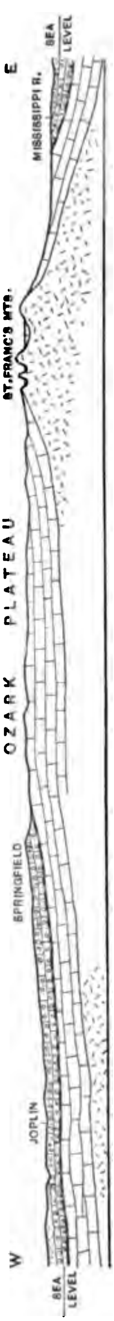

Fig. 177. — General west-east section through Joplin and the St. Francis Mountains. Shows the flat-topped dome of Cambrian and Ordovician limestones and pre-Cambrian rocks overlain by thin Devonian shale and Carboniferous sediments. (*U. S. Geol. Surv., Atl. Fol.* 148.)

(Fig. 176), but also includes portions of Arkansas, has four districts, viz.: (1) the southeastern Missouri, which is essentially lead-producing, and has been described on an earlier page; (2) the Central Missouri, containing small ore bodies with both lead and zinc (19); (3) the Missouri-Kansas, or southwestern Missouri, mainly a zinc-producing area; (4) northern Arkansas (1, 2), producing chiefly zinc, with some lead.

The third, or most important one, will be specially referred to.

The Ozark uplift or plateau is a low, rudely elliptical dome (Figs. 177, 178), lying mostly in southern Missouri and northern Arkansas. The Boston Mountains form the southern boundary, while it merges into prairie on the west and north, and the Gulf Plains on the east and southeast.

The rocks are mostly of sedimentary origin, but pre-Cambrian granites and porphyry form some of the peaks of the St. Francis Mountains. The Cambrian and Cambro-Ordovician dolomites, and limestone and sandstones underlying the central Ozark area, surround these mountains concentrically, and are in turn flanked successively by Devonian to Pennsylvanian rocks.

Joplin Area (18, 24, 25). — This is the most important area in the Missouri-Kansas district, and the generalized geological succession is shown in the accompanying diagram (Fig. 179).

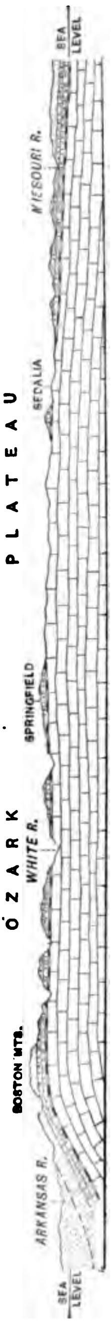

Fig. 178. — General south-north section through Springfield and Sedalia. Shows the flat-topped dome of Cambrian and Ordovician limestones overlain by thin Devonian and Carboniferous sediments. (*U. S. Geol. Surv., Atl. Fol.*, 148.)

The ore deposits of the Joplin district occur in large but very irregular masses of chert and limestone, which are unusually brecciated and cemented by, or impregnated with, dolomite, jasperoid, calcite, or sphalerite, and carry considerable amounts of sphalerite, galena, and iron sulphide. Of subordinate importance are chalcopyrite, greenockite, barite, and other minerals. Weathering develops oxides, carbonates, sulphates, and silicates of many of the above. They are found in the Boone formation and show a close association with certain forms of fracturing and brecciation.

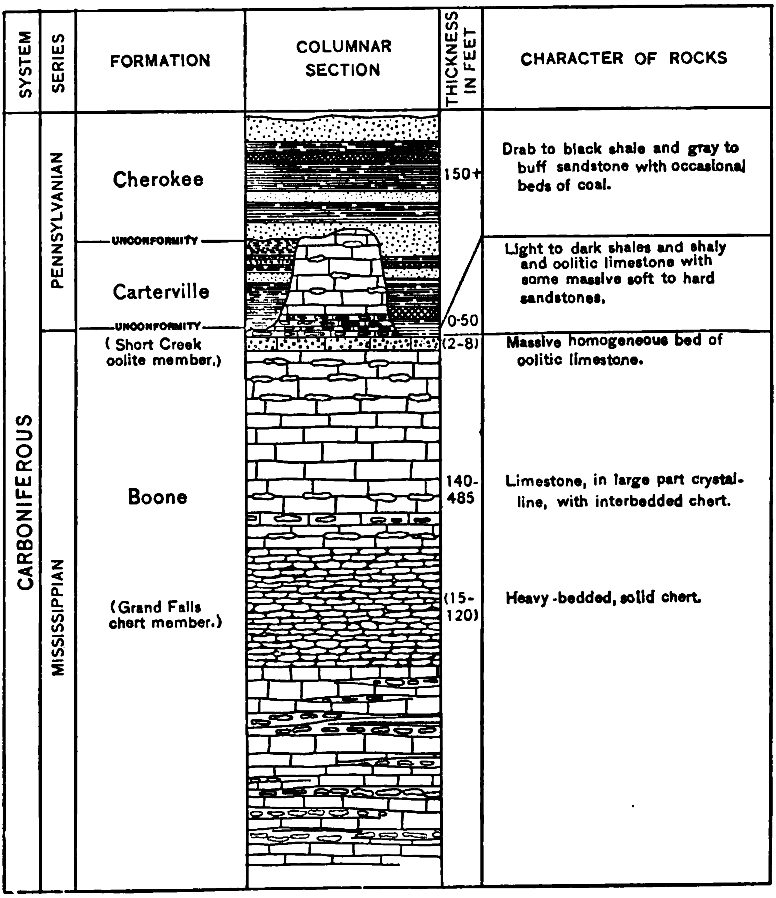
SYSTEM
SERIES
FORMATION
COLUMNAR SECTION
THICKNESS IN FEET
CHARACTER OF ROCKS
CARBONIFEROUS
PENNSYLVANIAN
MISSISSIPPIAN
Cherokee
150+
Drab to black shale and gray to buff sandstone with occasional beds of coal.
UNCONFORMITY
Carterville
0-50
Light to dark shales and shaly and oolitic limestone with some massive soft to hard sandstones.
UNCONFORMITY
(Short Creek oolite member.)
(2-8)
Massive homogeneous bed of oolitic limestone.
Boone
140-485
Limestone, in large part crystalline, with interbedded chert.
(Grand Falls chert member.)
(15-120)
Heavy-bedded, solid chert.

FIG. 179. — Generalized geologic section of the Joplin district. (*U. S. Geol. Surv., Atl. Fol.* 148.)

Jasperoid, which is the commonest gangue material, forms a cement of chert breccias or intercalations in practically undisturbed beds in sheet ground; it is usually of a dark gray to nearly black color when fresh, and the microscope shows it to be a fine-grained allotriomorphic aggregate of quartz (Fig. 180). Some have thought it to be a mud-like deposit that was later silicified, but it is more probably a siliceous replacement of limestone.

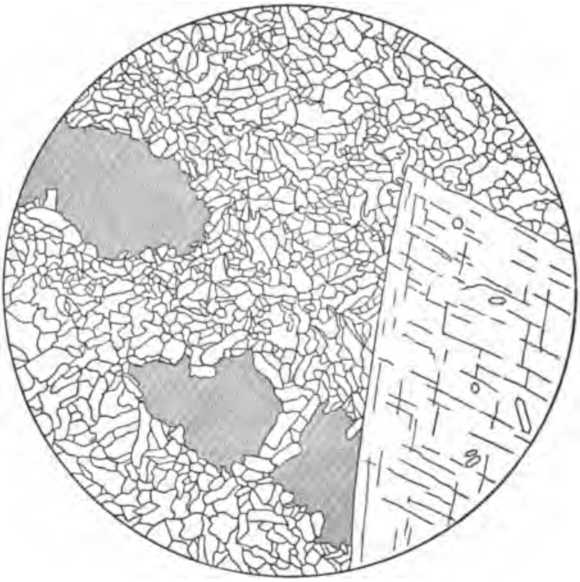

FIG. 180. — Photo-micrograph of jasperoid, showing fine granular aggregate of quartz, with sphalerite (shaded) and dolomite, the latter including minute quartz crystals. × 53. (*After Smith and Siebenthal.*)

The two important forms of ore body are *runs* and *sheet ground*. The runs are irregular, usually elongated, and in places tabular and inclined bodies of ore, associated with breccias produced, according to Smith, by minor faulting. They may be 10 to 50 feet wide, and of about the same depth.

In the commonest type of runs the ore-bearing breccias and massive secondary dolomite are juxtaposed along a steeply inclined contact plane, with the breccia on the hanging wall; behind the irregular zone of dolomite are unreplaced limestone and country rock, while back of the chert breccias are bedded cherts and subordinate limestones. The dolomite zone was formed by the metasomatism of limestone.

Sheet ground or blanket veins are nearly horizontal, tabular ore bodies, often of great lateral extent. The sulphides occur in part along bedding planes of cherts and in part in breccias resulting from slight folding and faulting of the bedded rocks. In the breccias the ore occurs as a cement or in jasperoid, while in the bedding planes it is in solution cavities or in jasperoid.

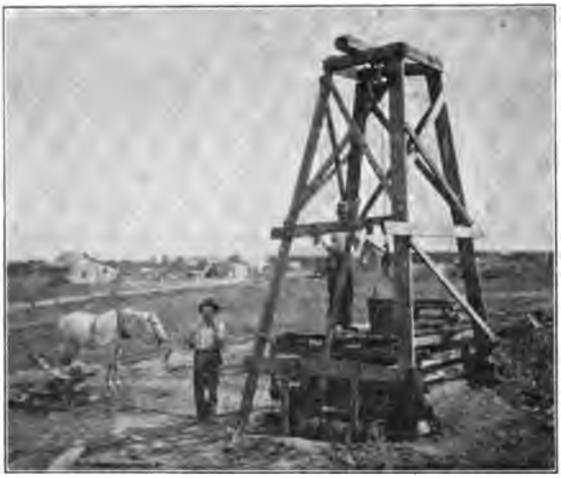

FIG. 181. — A typical small hoisting outfit in southwestern Missouri zinc region. (*H. F. Bain, Photo.*)

The sheet ground averages lower in ore contents than the runs, but is more uniform in character and being all at one level is more easily mined. Ore running 6 per cent is regarded as good, but when it falls to 2½ per cent it hardly pays to work it.

In the runs the galena is most abundant above, while the sphalerite occurs in the middle or lower portion, but in the sheet ground there is no such vertical separation.

The Joplin district is a most important producer of zinc, and while the content of this metal is low in the ore as it comes from the mines, still concentration raises it to about 58 per cent. The average tenor of lead is .5 to 1 per cent and of iron from 1 to 2 per cent. It assays about 30 per cent sulphur, and the remainder, besides a little cadmium, is silica.

An analysis representing the average of 3800 carloads of blende shipped from the Joplin district in the first part of 1904 is given by Ingalls as: Zn, 58.26; Cd, .304; Pb, .70; Fe, 2.23; Mn, .01; Cu, .049; $CaCO_3$, 1.88; $MgCO_3$, .85; SiO_2, 3.95; $BaSO_4$, .82; S, 30.72; total 99.773.

Origin of the Ores. — Most of the theories of the origin of these ores agree in considering that their concentration has been caused by circulating meteoric waters which have collected the ore particles from the limestones, although in one instance at least they seem to be associated with igneous intrusions (26 *a*).

Analyses of the limestones (26) show amounts of from .001 to .015 per cent of lead and zinc in the Cambro-Silurian magnesian limestones and Archæan rocks in the southeastern part of the Ozark region, and from .002 to .003 per cent in the Lower Carboniferous limestones.

These averages, expressed in different form, give 87 pounds of galena per acre in a one-foot layer, and 261 pounds of blende in the same volume of rock.

While agreeing as to the ultimate source, the different geologists who have studied these deposits reached somewhat varying conclusions as to their mode of concentration.

A brief résumé of these views is of interest partly because they indicate what varied conceptions may be based on the same evidence.

A. Schmidt[1] believed that dolomitization of the cherty limestones caused a shrinkage of the rock, and was accompanied by a deposition of the ore. Subsequent solution of the limestone caused a collapse of the residual chert, followed by further deposition of ore.

Haworth[2] suggested that after the chert and limestone were greatly fractured and dislocated, the sulphides were deposited, but that the deposition of secondary chert had begun before sulphide deposition ceased.

Winslow (26) thought that the breccia-filled caverns in the country rocks were formed by the percolation of surface waters, and that the metalliferous minerals were leached out of the overlying rocks by surface solutions and deposited in these breccias.

Jenney (23), however, believes the ores to have been deposited by ascending solutions.

Bain and Van Hise (18) after studying the district concluded that both ascending and descending waters were active. They also expressed the view that while the more important circulations have occurred in the Cambro-Silurian limestones and those of the Mississippian or Lower Carboniferous series, still the concentration process has been often repeated in many different horizons and at different depths.

According to their theory, then, the chemical changes which took place in the primary concentration of the ores were the oxidation of sulphides (in the limestones) to sulphates, the transportation of these in solution, and their reprecipitation as sulphides in favorable localities. The localization of the ore bodies has been due to the presence of fissures which permitted the mixing of the ore-bearing solutions, but the circulation of the latter has been limited in many instances by impervious beds of shale, and organic matter has served as a reducing agent. All of the ores are found to be closely associated with lines of subterranean seepage, and since the open character of the breccias favored circulation, much ore is found in them. Where folding has occurred, the water has also sought the troughs of synclines as in the Lake Superior district.

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[1] Mo. Geol. Surv., I, 1873–1874.

[2] Contribution to Geology of Lead and Zinc Mining Districts of Cherokee Co., Kansas.

In the section presented in the Ozark region, the Devono-Carboniferous shales and the undifferentiated Carboniferous shales afforded impermeable barriers to circulation. The former, where not faulted, held down the ascending solutions; but where absent or fissured, the solutions from the underlying Cambro-Silurian formation were able to pass upward into the Mississippian and impregnate them.

The Cambro-Silurian ores were first concentrated by deep circulation, and formed the disseminated ores. Later, when erosion cut away the Devono-Carboniferous capping, further concentration took place by descending solutions, giving rise to the ore bodies in crevices, breccias, and synclines.

Two concentrations have occurred in the Mississippian limestones.

Smith (25) agrees with Van Hise and Bain that the immediate sources of the ores are the various limestone formations below the Pennsylvanian. He assumes that the surface waters entered the Mississippian and Cambro-Silurian exposures to the south and east. Flowing westward along these beds, they then passed upward through fractures into the Mississippian limestones, mingling with the waters from these. Both flows are believed to have leached the smaller quantities of lead and zinc ores from the limestones through which they passed.

Precipitation of the ore occurred in the brecciated portions of the Boone formation (Fig. 179), and was caused by hydrocarbons which reduced the sulphates to sulphides. These hydrocarbons were set free by the dolomitization of the limestone, while CO_2 was set free by reaction between the hydrocarbons and the dissolved metallic compounds. The CO_2 thus liberated attacked some of the adjacent limestone, a part of which became replaced by silica.

The repetition of this cycle gave a continuous formation of dolomite, jasperite, and disseminated blende. Secondary concentration of the ore may have occurred.

There are certain points of similarity in the two preceding views.

Quite different, however, is the theory worked out by Buckley and Buehler (21). According to them there was an elevation of the region after the deposition of the Burlington limestone, followed by its extensive erosion and dissection. As a result of this process, great surface breccias of residual chert were probably produced on the hillsides and along the edges of the stream valleys. Subsidence during the Coal Measures period caused their burial under Pennsylvanian (Middle Carboniferous) sediments, where they now lie and have been identified by some (Bain) as fault breccias, but in reality are due to weathering.

They also of necessity lie along the horizon of what is now a marked unconformity, giving the semblance of faults. The metals and their ores are believed by these authors to have been derived from the overlying Pennsylvanian rocks, through the agency of descending surface waters.

Central Missouri district, containing small deposits of both lead and zinc. In this area the ore as far as exploited occurs rather in vertical crevices or chimneys than in breccias.

The northern Arkansas district, but partly developed, has many rich ores, occurring as bedded deposits (disseminations), veins (in faults or filling breccias), or as alterations (1, 2).

Upper Mississippi Valley. — This area embraces southwestern Wisconsin (48), eastern Iowa (12, 13), and northwestern Illinois (11), but the first-named state contains the most productive territory. The section in the Wisconsin area (48), which may be taken as typical, involves the following formations, beginning at the top: —

		FEET
Pleistocene	Loess, alluvium, and soil	7
Silurian	Niagara limestone	50
Ordovician	Maquoketa shale	160
	Galena limestone	230
	Platteville limestone (Trenton)	55
	St. Peter sandstone	70
	Lower Magnesian limestone	200
Cambrian	Potsdam sandstone	700
Pre-Cambrian	Crystalline rocks	

A bituminous shaly layer, known as the *oil rock*, occurs at the base of the Galena, and below it, or at the top of the Platteville, is a fine-grained limestone called the *glass rock*. While the series as a whole shows a very gentle southwest dip, there are a few low folds.

Most of the zinc obtained in the Rocky Mountain states is from complex ores.

Leadville is the most important producer, and is described below together with some others of minor importance.

Leadville District, Colorado (3–5). — This region lies on the western side of the Mosquito Range at the headwaters of the Arkansas River in south-central Colorado, while the town of Leadville is situated on the western spurs of the range overlooking the Arkansas Valley. The latter is bounded by the Sawatch Range on the west.

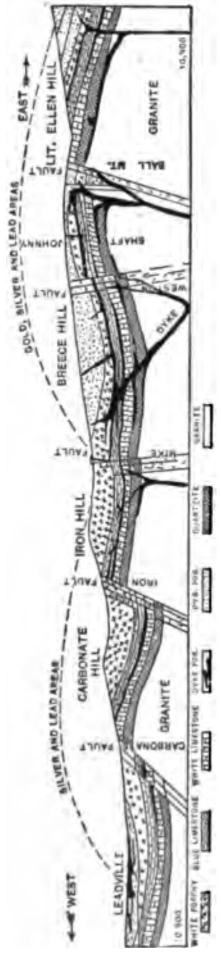


FIG. 184. — Ideal section of Leadville, Colo., district. (*After Warwick, Min. Mag., XI.*)

The mines which have made Leadville famous for its production of silver, gold, lead, zinc, iron, and manganese are mostly high up on the ridge and from 2 to 3 miles east of the town, but in later years developments have been spreading westward towards the valley. The district was formerly placed among the lead-silver camps, but since the rich bodies of silver-bearing lead carbonate have become exhausted a large tonnage is obtained from the lead-zinc sulphide ore bodies deeper down, and for that reason it is placed here, although it is not to be understood from this that other metals are not produced there in quantity.

The Sawatch Range is an oval mass of gneisses, granites, and schists on whose flanks rest the Cambrian and later sediments, dipping away from the range on all sides.

The Mosquito Range (elevation 13,000 to 14,000 feet) is composed mainly of Paleozoic rocks, with some Mesozoic deposits on its eastern flanks, while between these beds are sills and laccoliths of igneous rocks, whose intrusions occurred before the uplift of this region.

This uplift was formed by an east-to-west thrust which pushed the beds up into folds against the Sawatch Range and later faulted them (Fig. 184).

In consequence, therefore, of folding, faulting, igneous intrusions,

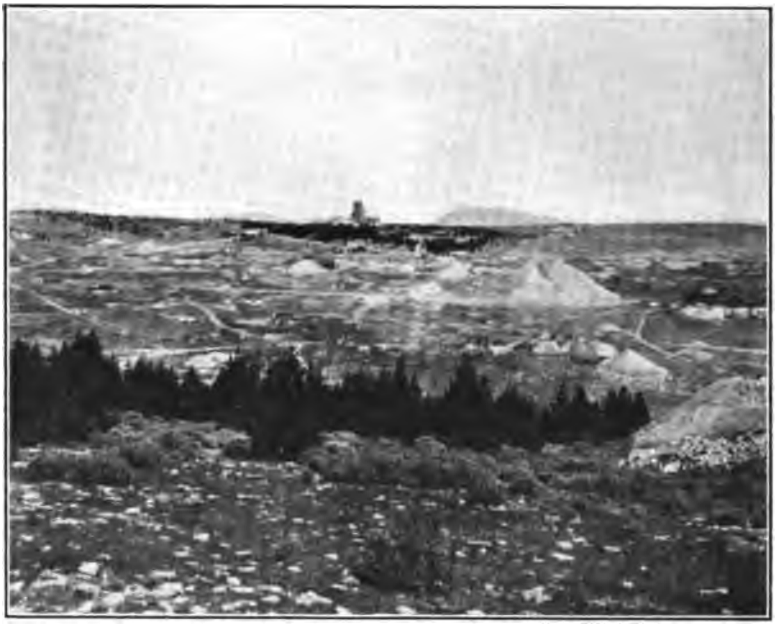


FIG. 1. — View from top of Carbonate Hill, Leadville, Col., looking towards Iron Hill. The valley in center ground marks position of the Iron fault. Shaft house is that of Tucson shaft, and ridge in distance fault scarp of Mosquito Range. (*H. Ries, photo.*)

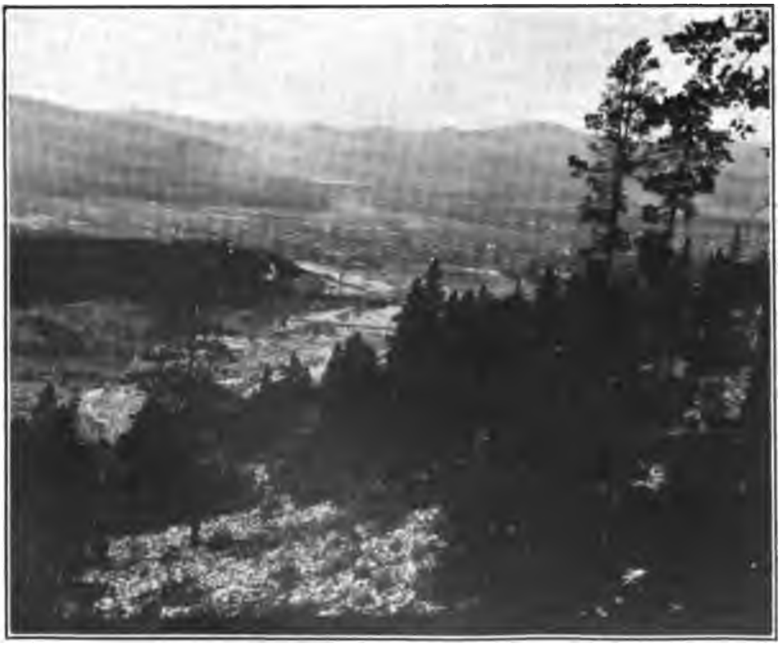


FIG. 2. — View from south end of Carbonate Hill, Leadville, Colo., overlooking California Gulch in foreground, and town of Leadville in the valley. Sawatch Range in distance. (*H. Ries, photo.*)

and detrital material, the structural geology of Leadville affords a somewhat complex problem.

The geological section best shown in Carbonate Hill perhaps is as follows: —

LOCAL NAME	AGE	ROCKS	THICKNESS
White porphyry .	Pre-Cretaceous	White rhyolite porphyry	800′
Blue limestone .	Lower Carboniferous	Blue-gray dolomite	200′
Gray porphyry .	Pre-Cretaceous	Gray monzonite porphyry	50′
Parting quartzite	Devonian	Coarse quartzite	30′
White limestone	Silurian	Drab siliceous dolomite limestone	160′
Lower quartzite	Cambrian	Mostly white quartzite	160′
Granite	Basement complex of pre-Cambrian age	Granite and gneiss	——

The fracturing and displacement of these rocks has resulted in the formation of a number of great fault blocks, which in their eroded form stand out as prominent hills, known as Breece, Iron, Carbonate, Fryer, etc. (Fig. 184).

The ore bodies occur mainly as great replacement masses in the blue and white limestones, and in the Devonian quartzite; but in addition there have been discovered fissures and cavities in the Cambrian quartzite which carry ore that has evidently been deposited from solution and not by replacement (Fig. 185). While these fissures are known to be connected with the Silurian limestone ores, they have not yet been traced to the granite.

Gold ores are found on Breece Hill to the eastward, but these belong to a different type.

The original ore of the district consisted of lead, zinc, iron, and copper sulphides carrying silver and gold, the proportions of the several metals varying in different parts of the district.

For some years the oxidized ore bodies of cerussite and cerargyrite in a matrix of iron and manganese oxide formed the main stay of the camp, but the practical exhaustion of these and the discovery of the large sulphide bodies at lower levels has greatly changed things. The camp now is turning out a large tonnage of lead and zinc sulphides which may carry gold and silver, manganese ores from oxidized deposits on Carbonate Hill, some copper sulphides, and some bismuth ores.

The origin of these ores has been discussed by several geologists, Emmons and Blow being among the earlier ones.

Emmons, in his classic monograph on this district (4), expressed the following views regarding the origin of the ore deposits: (1) that they have been derived from aqueous solution; (2) that this solution came from above; (3) that the ores derived their metallic contents from the neighboring eruptive rock. He further adds that these statements are not intended to deny the possibility that the metals may have originally come from depth, nor to maintain that they were necessarily derived entirely from eruptive rocks at present in immediate contact with the deposit. (4) The ores were deposited by replacement of the country rock. (5) They are of later age than the porphyry sheets, but were introduced before the faulting of the region occurred.

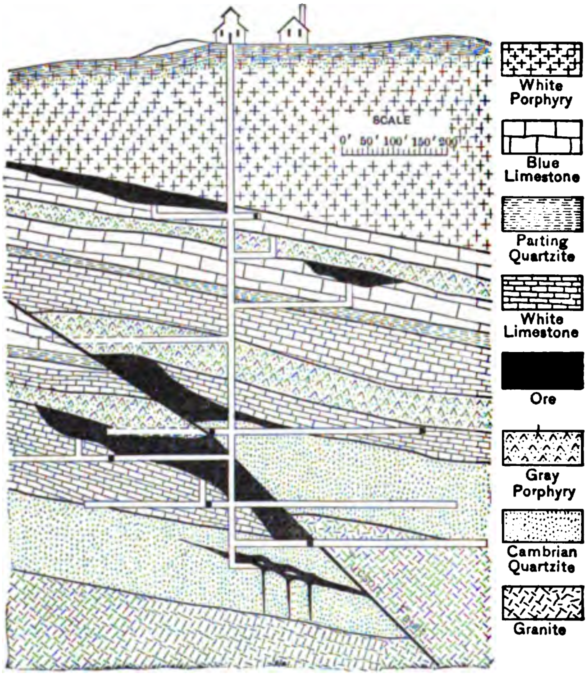


Fig. 185. — Vertical section along line *AB*, Fig. 186. Tucson shaft, Leadville, Col. (*After Argall, Eng. and Min. Jour., LXXXIX.*)

These views are not agreed to entirely by all persons familiar with the district, and there is a tendency among many engineers who have a more or less intimate knowledge of the region to feel that the ores may have been brought in by solutions ascending directly from the granite, a theory which they regard as being strengthened by the finding of fissure ores in the Cambrian quartzite (Figs. 185, 187).

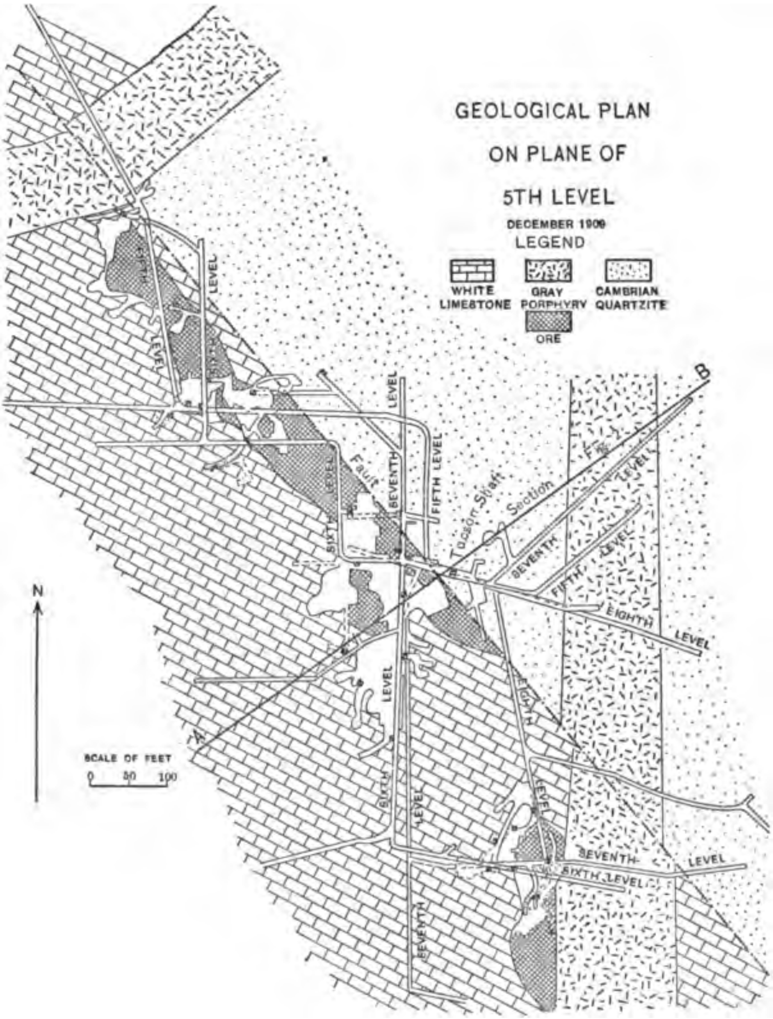


FIG. 186. — Geologic plan of fifth level and workings, Tucson shaft, Leadville, Col. (*After Argall, Eng. and Min. Jour., LXXXIX.*)

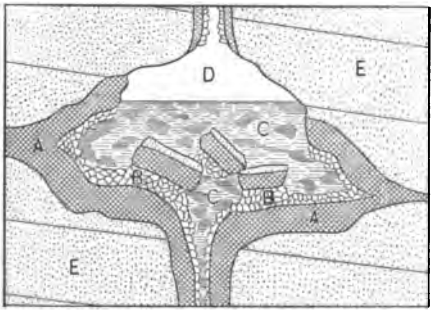
We must remember, of course, that since Emmons' work was done the district has been greatly and more deeply developed, thus affording opportunity for more extended investigation.

The following classification of the Leadville output for 1908[1] will give some idea of the relative importance of the different kinds of ores:—

CLASSIFICATION OF LEADVILLE ORES

		QUANTITY	PERCENTAGE
		Short Tons	
Siliceous	Gold-silver	25,741	6
	Total siliceous	25,741	6
Sulphide	Zinc-iron-lead (zinc blende-pyrite, with a little galena)	95,306	23
	Iron pyrite, with a little copper, gold, silver, and lead)	151,284	37
	Total sulphide	246,590	60
Oxide	Lead	24,616	6
	Iron-manganese (silver)	111,764	28
	Total oxide	136,380	34
	Grand total	408,711	100

The chief sulphide was iron pyrite, carrying a little copper, gold, silver, and some lead, and the bulk of this was smelted directly. The higher-grade zinc sulphide ore was shipped to zinc smelters without concentration, but most of the zinc sulphide was separated magnetically or concentrated at Leadville, Canyon City, or Denver. The iron-oxide ore carried about 10 per cent manganese and a low per cent of lead. That portion of the sulphide ore which was milled averaged 32 cents gold, 1.9 fine ounces silver, 2.8 per cent lead, 13.34 per cent zinc. The average assay of the concentrate showed 62 cents gold; 3.74 fine ounces silver, 5.5 per cent lead; and 26.10 per cent zinc. Seventy-nine per cent of all the tonnage of ore was sent direct to the smelter.



A, pyrite and blende; B, galena; C, mud deposit; D, open cavity; E, Quartzites.

FIG. 187. — Cavities in Cambrian quartzite, Tucson shaft, Leadville, Col. (*After Argall.*)

Even in former years Leadville was a mining camp of great importance, having indeed given Colorado its first serious start as a mining state. From an area of about a square mile the output of silver was for a number of years greater than that of any foreign country except Mexico, and during the same period the production of lead was nearly equal to that of England and greater than that of any European country excepting Spain and Germany. Although regarded originally as a silver camp, it really ceased being such nearly fifteen years ago, and is now an important producer of at least eight metals, of which five or six are sometimes all obtained from the same group of properties. It will thus be seen that the successful marketing of one may affect all the others. Leadville began as a gold camp in 1860, when a placer deposit of gold was found in a gulch near there and several million dollars' worth of metal were extracted, resulting in the establishment of a flourishing town called Oro, which, however, soon lost its importance when the gold began to be exhausted. Not until 1875 was the carbonate of lead, which has since been so important, actually recognized.

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[1] U. S. Geol. Surv., Min. Res., 1908.

Other Western Occurrences (32, 42, 43). — Both zinc and lead are supplied by the mines at Creede, Colorado, where the ore is found in fissure veins carrying galena and blende in a quartz gangue.

The deposits in the Magdalena Mountains, New Mexico, have been important producers of lead ores, and are now an even more important source of supply of zinc ore. These deposits which are of contact-metamorphic origin occur in limestones near their boundary with granite porphyry.

Another producer of some importance is the Horn Silver mine at Frisco, Utah. The ore here occurs in a contact vein between rhyolite and limestone. The oxidized ore is chiefly anglesite (argentiferous) and barite, but below it passes into lead-zinc sulphides, and the mine is now an important producer of zinc.

Additional occurrences are referred to under Lead-Silver.

Uses of Lead and Zinc. — Both of these are important base metals; although in value of production they rank below gold, silver, copper, and iron, neither do they come into competition with these, for they lack the high tenacity of iron and steel, the conductivity of copper, and the value resulting from scarcity possessed by gold and silver. They are of value, however, on account of their high malleability and the application of their compounds for pigments.

Uses of Lead. — Lead finds numerous uses in the arts, the most important being for white lead. Litharge, the oxide of lead, is used not only for paint, but also somewhat in the manufacture of glass, although red lead is more frequently employed instead.

A further use of lead is for making pipe for water supply, sheet lead for acid chambers, and shot.

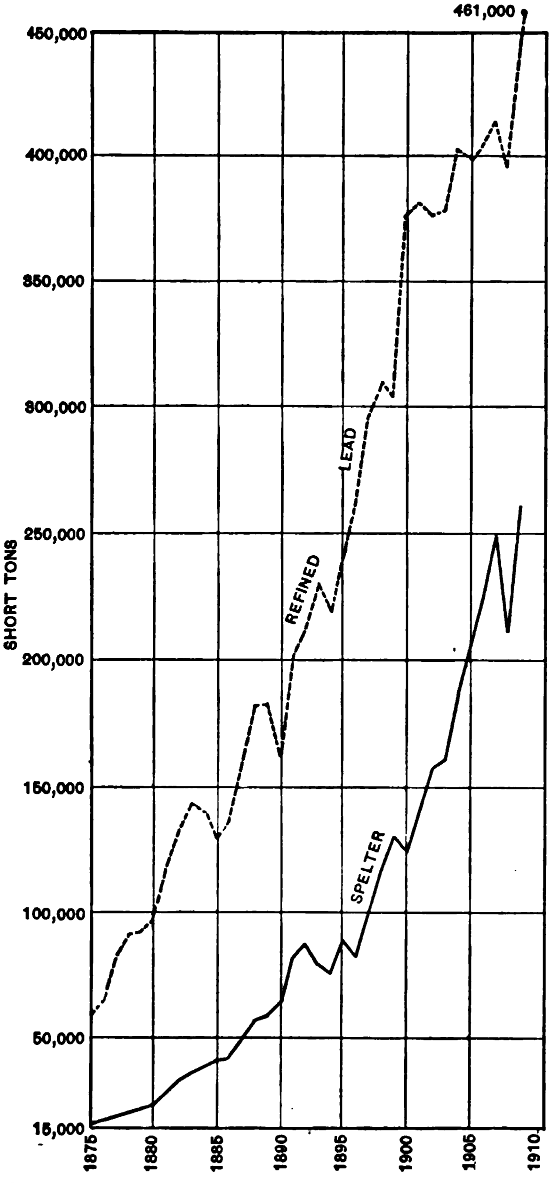

FIG. 188. — Chart showing production of refined lead and spelter in the United States from 1875 to 1909. (*U. S. Geol. Surv.*)

Among the alloys formed by lead are type metal (lead, antimony, and bismuth, with copper, or iron), white metal, organ pipe composition, and fusible alloys used in electric lighting.

In addition to these, the acetate, carbonate, and other compounds are used in medicine. In smelting, lead is used to collect the gold and silver, and the bulk of the lead of commerce is obtained as a by-product in the smelting of the precious metals.

Uses of Zinc. — Metallic zinc is used for a variety of purposes, partly owing to its slight alteration in air, and secondly, because it can be rolled into thin sheets. In this condition it is used extensively for roofing and also for plumbing, and as a coating to iron this metal is extensively called for in galvanizing. It is also used for cyaniding gold.

One of the most important applications is for making brass, which is ordinarily composed of from 66 to 83 parts of copper and 27 to 34 parts of zinc. The composition varies, entirely depending on the use to which it is to be put, and, with the variation in proportion, the color becomes more golden, or whiter, according as the percentage of copper is increased or decreased. With an increase in the amount of zinc, the alloy becomes more fusible, harder, and more brittle.

White metal is an alloy of zinc and copper in which zinc predominates, and which is often employed for making buttons. Imitation gold is also made by alloying zinc with a predominance of copper, varying from 77 to 85 per cent of the mass, and this is in common use as " gold foil " for gilding. Zinc is also made use of in the construction of electric batteries.

German silver has 60 parts copper, 20 zinc, and 20 nickel. Its use is for mathematical and scientific instruments.

Zinc is used wholly or in part as the base of four pigments, viz. zinc oxide, leaded zinc oxide, zinc-lead oxide, and lithophone. All of these can be made directly from the ore, and the first three usually are. Zinc oxide is the most important of the four. Lithophone is an intimate mixture by chemical precipitation of zinc sulphide and barium sulphate.

Production of Lead and Zinc. — The production of refined lead and spelter in the United States from 1875 to 1909 are given in the chart, Fig. 188. Other statistics of production are given in the tables on the following page.

The imports of manufactured, block, and pig zinc amounted to $90,389 worth in 1908 as against $244,730 in 1907. The total amount of zinc ore imported in the year 1908 was 53,757 short tons, as against 103,117 in 1907. The total value of the exports of ore and manufactured zinc in 1908 were valued at $1,683,887. The imports of zinc oxide in 1908 amounted to 2,423 short tons, while the exports in that same year were valued at $845,070.

The total amount of lead imported in 1908 was 264,978 pounds, while the exports amounted to 777,350 pounds for the same period.

PRODUCTION OF PRIMARY SPELTER IN THE UNITED STATES IN 1906–1908, APPORTIONED ACCORDING TO SOURCE OF ORE, IN SHORT TONS

SOURCE	1906		1907		1908	
	QUANTITY	PERCENTAGE OF TOTAL	QUANTITY	PERCENTAGE OF TOTAL	QUANTITY	PERCENTAGE OF TOTAL
Arizona	64	0.032	77	0.03	152	0.08
Arkansas	1,801	.90	1,911	.85	2,002	1.05
California	—	—	140	.06	27	.01
Colorado	32,456	16.25	26.077	11.66	24,885	13.05
Idaho	573	.29	3,508	1.57	581	.30
Illinois	282	.14	1,446	.65	298	.16
Iowa	201	.10	220	.10	516	.27
Kansas	3,902	1.96	13,850	6.19	8,628	4.52
Kentucky	335	.17	358	.16	341	.18
Maine	—	—	1	.0004	—	—
Missouri	130,348	65.27	141,824	63.39	123,655	64.83
Montana	1,415	.71	—	—	900	.47
Nevada	1,768	.88	1,692	.76	398	.21
New Jersey	11,206	5.61	13,573	6.07	6,926	3.63
New Mexico	555	.28	136	.06	134	.07
Oklahoma	—	—	719	.32	2,235	1.17
Tennessee	124	.06	181	.08	341	.18
Texas	8	.004	16	.0007	—	—
Utah	2,449	1.23	1,972	.88	282	.15
Virginia	1,143	.57	771	.34	910	.48
Washington	7	.004	—	—	—	—
Wisconsin	11,057	5.54	15,273	6.83	17,538	9.19
Total from domestic ores	199,694	100.00	223,745	100.00	190,749	100.00
Foreign:						
British Columbia	201	.80	545	2.09	2,425	12.33
Mexico	24,875	99.20	25,570	97.91	17,250	87.67
Total from foreign ores	25,076	100.00	26,115	100.00	19,675	100.00
Grand Total	244,770	—	249,860	—	210,424	—

PRODUCTION OF SPELTER IN THE UNITED STATES, 1904–1908, APPORTIONED ACCORDING TO LOCALITY IN WHICH SMELTED, IN SHORT TONS

	1904	1905	1906	1907	1908
Illinois	47,740	46,606	47,939	56,056	50,244
Kansas	107,048	114,287	129,564	134,108	99,298
Missouri	12,150	11,844	11,077	11,732	10,201
Oklahoma	—	—	—	5,035	14,864
Other States[1]	19,764	31,112	36,190	42,929	35,817
Total	186,702	203,849	224,770	249,860	210,424

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[1] Includes New Jersey, Pennsylvania, Virginia, West Virginia, and Colorado.

Lead Content of Ores smelted by the Works in the United States, 1903 to 1905, by States, in Short Tons

State or Territory	1903	1904	1905
Colorado	45,554	51,884	56,638
Idaho	99,590	108,854	99,027
Utah	51,129	56,470	44,996
Montana	3,303	3,635	2,207
New Mexico	613	1,363	1,232
Nevada	2,237	1,873	2,206
Arizona	1,493	1,499	2,091
California	55	163	116
Washington	538	622	56
Ore., Alas., S. Dak., Tex.	1,765	41	101
Mo., Kas., Wis., Ill., Ia., Va., Ky.	86,597	92,275	104,058
Total lead content American ores smelted	292,874	318,679	312,728
Content Mexican ores	56,890	24,952	—
Content Canadian ores	253	11	—
Content miscellaneous or unknown	2,831	1,113	—

Sources of Primary Lead smelted or refined in the United States, 1906–1908, in Short Tons

Source of Ore	1906		1907		1908	
	Quantity	Percentage of Total	Quantity	Percentage of Total	Quantity	Percentage of Total
Domestic ore:						
Alaska	8	0.002	—	—	3	0.001
Arizona	2,884	.83	2,340	0.64	1,464	.47
Arkansas	—	—	15	.004	—	—
California	432	.12	854	.23	515	.17
Colorado	50,497	14.51	48,876	13.43	28,728	9.28
Georgia	—	—	2	.0005	—	—
Idaho	117,117	33.65	112,569	30.94	98,464	31.82
Illinois	572	.16	498	.14	363	.12
Iowa	270	.08	225	.06	110	.03
Kansas	1,932	.56	1,798	.49	2,293	.74
Kentucky	44	.01	75	.02	—	—
Missouri	111,075	31.91	122,856	33.77	122,451	39.57
Montana	2,485	.71	2,035	.56	2,320	.75
Nevada	1,669	.48	3,380	.93	3,796	1.23
New Mexico	640	.18	1,927	.53	586	.19
Oklahoma	—	—	404	.11	1,409	.45
Oregon	—	—	—	—	7	.002
South Dakota	—	—	—	—	13	.003
Tennessee	11	.003	16	.004	—	—
Texas	25	.011	10	.002	42	.01
Utah	56,260	16.16	61,699	16.96	42,455	13.72
Virginia	—	—	82	.02	13	.004
Washington	46	.015	281	.08	391	.13
Wisconsin	1,753	.50	3,551	.98	4,013	1.30
Undistributed	380	.109	355	.10	36	.01
Zinc residues	2,053	—	1,318	—	1,290	—
Total from domestic ore	350,153	100	365,166	100	310,762	100
Foreign ore:						
Africa	—	—	323	—	—	—
British Columbia	7,238	—	5,793	—	341	—
Central America	112	—	—	—	12	—
China	18	—	—	—	4	—
Mexico	21,435	—	36,749	—	38,729	—
South America	—	—	911	—	1,186	—
Other foreign	—	—	149	—	—	—
Foreign base bullion:						
Mexico	39,743	—	32,924	—	57,489	—
Total from foreign ore and base bullion	68,546	—	76,849	—	97,761	—
Grand total, derived from all sources	418,699	—	442,015	—	408,523	—

The World's Production of Spelter, 1907–1908, in Short Tons

Country	1907	1908
Australia	1,098	1,198
Austria and Italy	12,522	14,063
Belgium	170,307	181,851
France and Spain	61,438	61,512
Germany:		
Rhine district	77,459	80,670
Silesia	152,611	158,328
Great Britain	61,286	60,029
Holland	16,526	19,017
Poland	10,735	9,740
United States	249,860	210,424
Total	813,842	796,832
United States percentage of world's production	30.7	26.4

The World's Production of Lead, 1907–1908, in Short Tons

Country	1907	1908
Australia	106,923	131,376
Austria-Hungary	16,975	16,118
Belgium	28,417	33,231
Canada	23,778	23,846
France	25,353	27,600
Germany	157,156	181,167
Great Britain	30,203	33,120
Greece	15,212	17,664
Italy	25,243	28,704
Japan	3,858	3,312
Mexico	79,366	121,440
Russia	110	110
Spain	204,848	202,253
Sweden	772	883
Turkey in Asia	11,464	13,027
Other countries	220	552
United States	365,166	310,762
Total	1,095,064	1,145,165
United States percentage of world's production	33.3	27.1

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CHAPTER XVIII

SILVER-LEAD ORES

The silver-lead ores form a large class, which are widely distributed in the Cordilleran region, and not only supply most of the lead mined in the United States, but in addition may also, and often do, carry variable quantities of silver, gold, and copper.

The deposits as a whole present a variety of forms. The associated rocks are often faulted, and the ore bodies are commonly oxidized above, so that the altered portions require different metallurgical treatment from the sulphide ores found below. Secondary enrichment has in some cases raised the grade of the ore. Deposits of this class are prominent in Colorado, Idaho, and Utah, but are also known in New Mexico, Montana, Wyoming, Nevada, Arizona, California, and South Dakota. Idaho is the largest producer of silver-lead ores, but they average only one third silver, while those of Colorado average three quarters silver, and those of Utah about two thirds silver. A few of the more prominent occurrences are mentioned.

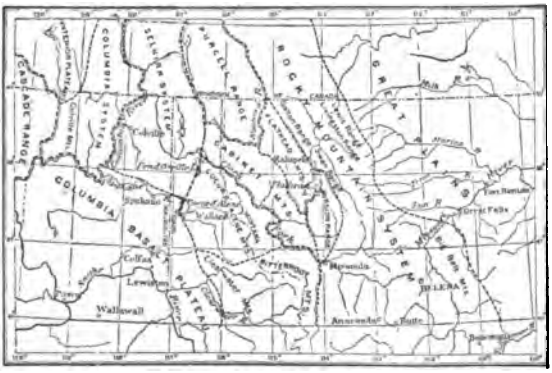

FIG. 189. — Map showing location of Cœur d'Alene, Ido., district. (*After Ransome, U. S. Geol. Surv., Prof. Pap. 62.*)

Cœur d'Alene, Idaho (14). — The Cœur d'Alene district (which is really made up of several local mining districts) lies in Shoshone County, mostly on the western slope of the Cœur d'Alene Mountains. Wallace is the principal town, but there are several smaller ones, as Wardner, Mullan, Burke, Mace, Gem, and Murray.

The prevailing rocks here are a thick (10,000 ft.), apparently

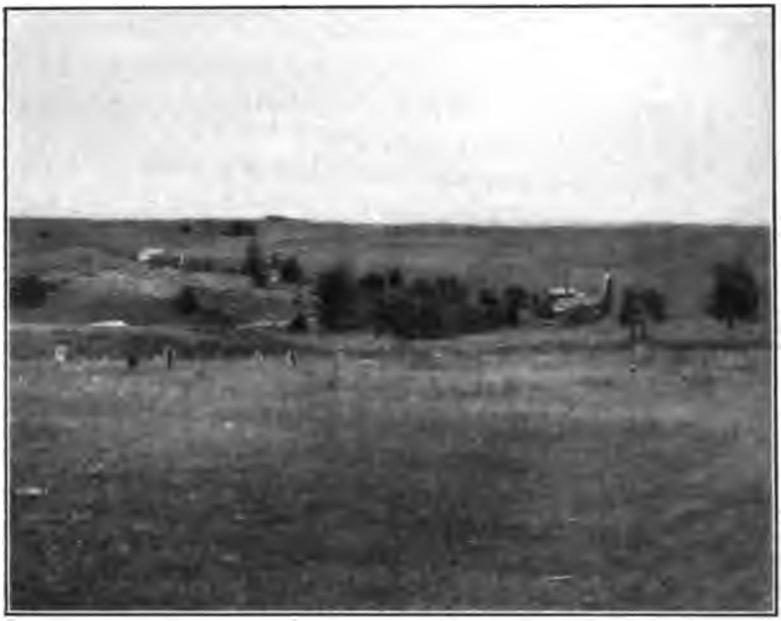

FIG. 1. — View near Linden in Wisconsin lead and zinc district. (*H. Ries, photo.*)

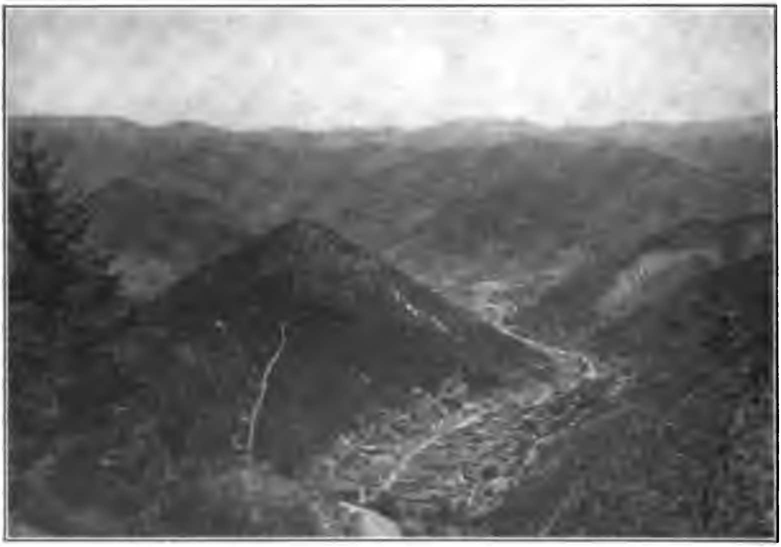

FIG. 2. — View looking north over the Cœur d'Alene Mountains from the Stemwinder tunnel above Wardner. Shows mature dissection of plateau-like uplift. Town of Wardner in foreground. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 62.)

conformable series of shales, sandstones, and some limestones of Algonkian age, which on the west are faulted down against granitic and gneissic rocks, but extend some distance to the eastward.

The condensed section is as follows:—

	Feet
Striped Peak shales and sandstones	1,000+
Wallace sandstones, shales and limestones	4,000
St. Regis shales, and sandstones	1,000+
Revett white quartzite	1,200
Burke shales and sandstones	2,000
Prichard shales and sandstones	8,000
	17,200+

The igneous rocks include some small intrusive stocks of monzonite, and a few dikes of diabase and lamprophyre-like rocks, but the age of all is uncertain.

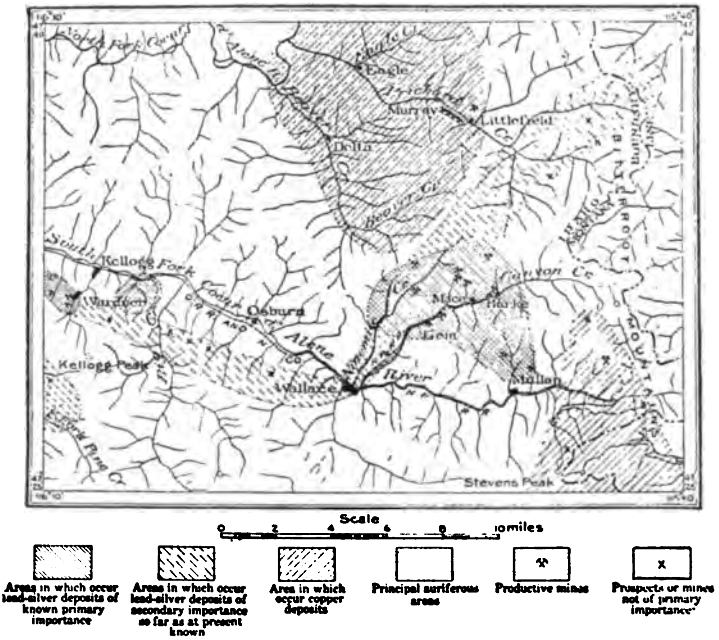
Eagle
Prichard Cr
Murray
Littlefield
Delta
Beaver Cr
South Fork
Kellogg
Wardner
Osburn
Coeur d'Alene
River
Wallace
Kellogg Peak
Gem
Burke
Canyon Cr
Mullan
Stevens Peak
Scale
0 2 4 6 8 10 miles
Areas in which occur lead-silver deposits of known primary importance
Areas in which occur lead-silver deposits of secondary importance so far as at present known
Area in which occur copper deposits
Principal auriferous areas
Productive mines
x
Prospects or mines not of primary importance

Fig. 190. — Geologic map of Cœur d'Alene, Ido., district. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 62.)

The rocks show a series of complex, sometimes overturned, folds as well as extensive faults, and slaty cleavage has been developed in all except the quartzite.

The largest ore bodies, although wonderfully persistent, are likely to become poor at depths ranging from 1000 to 2000 feet. Three types of ore bodies are recognized, and of these, which are described below, the first is the most important.

1. Lead-silver deposits, consisting essentially of metasomatic fissure veins, formed in greater part by replacement of siliceous sedimentary rocks, along zones of fissuring, and carrying mainly galena and siderite. The galena may first replace the quartzite, or siderite may replace quartzite first and then be replaced by galena.

Pyrite and sphalerite are always present, and tetrahedrite, if found, indicates high silver values, but chalcopyrite is rare. Oxidized ores occur above.

The lead-silver veins, which lie mainly in that portion drained by the south forks of the Cœur d'Alene River and its tributaries, occur mostly in the Burke formation, while a few are found in the Revett, Wallace, St. Regis, and Prichard.

The average contents of ore in silver is a little over half an ounce to each per cent of lead per ton. In 1903–1904 the Bunker Hill and Sullivan averaged 8.8 per cent of lead and 3.9 ounces silver, while first-class concentrates from the same mine averaged 55 per cent lead and 19.5 ounces silver. An ore of 4.5 per cent lead and 2.7 ounces silver is unprofitable to work. The bulk of the ore ranges from 3 to 14 per cent lead and 2.5 to 6 ounces silver per ton. Most of the ore in the district is concentrated to 50 or 60 per cent lead.

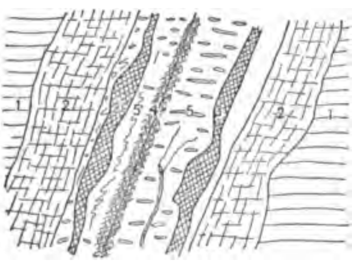

FIG. 191. — Section of lead-silver vein, Cœur d'Alene, Ido. (1) Country rock. (2) Sheared rock. (3) Galena and siderite. (4) Fissure with fine-grained galena. (5) Barren, silicified country rock. (*After Finlay Amer. Inst. Min. Engrs., XXXIII.*)

The rich ores and concentrates may be sent to Tacoma; San Francisco; Salida, Colorado; Helena, Montana; etc.

In the mines, the galena is shown to have a vertical range of at least 2600 feet.

2. Gold deposits, including bed veins, fissure veins, and placers formed in at least two periods.

The productive gold-quartz veins occur near Murray and are bed veins, following stratification planes of the Prichard formation. They are usually a foot or two in width and carry quartz, gold, pyrite, galena, sphalerite, and chalcopyrite, with occasional bunches of scheelite. The average value of the ore probably does not exceed over $7 per ton.

3. Copper deposits, consisting either of impregnations along certain quartzitic beds or metasomatic fissure veins. Only the former type is of commercial importance, and at the Snowstorm mine it forms an im-

pregnated zone with a maximum width of 40 feet. The ore is chalcopyrite, bornite, chalcocite, etc., and the greater part runs 4 per cent copper, 6 ounces silver, and .1 ounce gold. The ore as shipped is worth $9 to $10 per ton.

Origin of lead-silver ores. — It is believed that the association of the ore with fissures and the absence of irregular deposits indicate that it has been deposited by ascending solutions, moreover the mineralogical composition of the ore suggests its precipitation from hot solutions under high pressure.

These solutions are thought to have been given off by the monzonite in vaporous form, producing contact metamorphism and depositing ores rich in sphalerite and pyrrhotite associated with garnet and biotite, found in some parts of the district.

Farther away from the intrusive the lead-silver ores were deposited. It is probable that the solutions entered the stratified rocks carrying ferrous carbonate and lead sulphide, and not only filled the open spaces but replaced the quartzite.

The first prospecting occurred in this district about 1878, and subsequent discoveries in 1879 started a rush to this region, but this centered round the placers, which commanded the most attention even up to 1885; but in the following year the miners awoke to an appreciation of the lead-silver deposits, and the building of a railroad into the district in 1887 gave a great impetus to the lode-mining industry. Since then the Cœur d'Alene has been an important producer, in spite of severe though temporary setbacks due to labor troubles in 1892 and 1899.

Aspen, Colorado (15, 10). — The ores are oxidized and occur in highly folded and faulted Carboniferous limestone, although the section involves rocks ranging in age from Archæan to Mesozoic. Two quartz porphyries, one at the base of the Devonian, the other in the Carboniferous, are present, but bear no special relation to the ore.

At the close of the Cretaceous the rocks were folded into a great anticline, with a syncline on its eastern limit, which passed into a great fault along Castle Creek west of the mines. Contemporaneous with the folding there were also produced two faults parallel to the bedding of the Carboniferous dolomite, while at the same time much cross faulting occurred. The ore is found chiefly at the intersection of these two sets of fault planes, and Spurr believes that the ores were deposited by magmatic waters ascending vertically along faults, and were precipitated by a reaction between the solutions and certain wall rocks, chiefly shale. Mingling of solutions at the intersection of fissures also played an important rôle in the formation of the ore. This stronger deposition of the ore at the intersection of fault planes was thought by Weed to be due to secondary enrichment, but Spurr finds little evidence of secondary sulphide formation.

On account of the intimate association of the dolomite, quartz, and barite with the ore their origin is considered as similar.

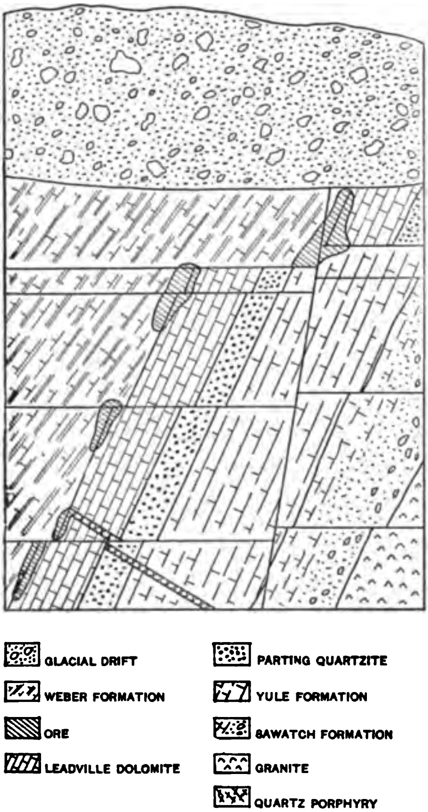

FIG. 192. — Section of ore body at Aspen, Col. (*After Spurr, U. S. Geol. Surv., Mon. XXXI.*)

The ores are peculiarly free from other metals except lead, and the rich polybasite (Ag_9SbS_6) ores of Smuggler Mountain do not contain even this.

The mining camp of Aspen started in 1879, but its development for a time was much retarded by lawsuits. The richer ore bodies were not discovered until 1884, and then by underground exploration, for owing to the heavy mantle of glacial gravels their outcrops were hidden. Since also the ore carries no iron or manganese, as do the Leadville ores, its outcrop may be inconspicuous.

The railroads did not reach the camp until 1887, so that during the first few years of its history the ore had to be carried out on burros.

In both Aspen and Smuggler Mountains long tunnels have been run for drainage and hauling purposes. The Cowenhoven tunnel, which is the largest of these, is over 8300 feet long, and taps a number of mines. Aspen was one of the first mining camps in the West to install electric machinery for hoisting, haulage, etc., and the current was cheaply supplied by the neighboring water power. One shaft 1000 feet deep is operated electrically.

At the present day the larger ore bodies are worked out, but the camp is still an active producer. From 1881 to 1895 it produced $63,653,989 worth of silver.

Rico, Dolores County, Colorado (3, 12, 13). — In this region the mountains, which are the remains of the structural dome rising above the Dolores plateau lying in the San Juan region, contain a series of sedimentary beds ranging from Algonkian to Jurassic in age, which have been uplifted partly by the intrusion of igneous rocks, as stocks, sills, and dikes, and partly by upthrows due to faulting.

The ore occurs as lodes, replacements in limestones, stocks, and blankets, the last consisting usually of deposits lying parallel to the planes of bedding or to the sheets of igneous rock, and known locally as "contacts," although not such in the true sense.

The four types of deposit mentioned may pass into each other. Most of the ore in the district has, however, come from the blankets, and the bulk of this has been found in the Carboniferous, especially in the Hermosa formation, a striking feature of the deposits being their limited vertical range.

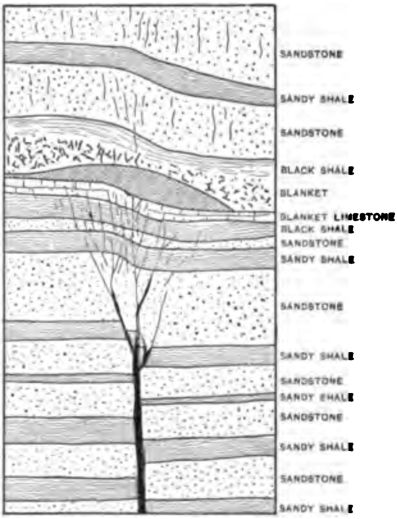

Fig. 193. — Diagrammatic section across a northeasterly lode at Rico, Col., showing "blanket" of ore. (*After Ransome, U. S. Geol. Surv., 22d Ann. Rept.*)

The ores are primarily galena, often highly argentiferous and associated with rich silver-bearing minerals. In many deposits the more or less complete oxidation of the silver ores has resulted in powdery masses, often very rich in silver. Below the zone of oxidation, the veins have not been successfully worked.

The bulk of the ores can be roughly divided into pyritic ores, usually low grade, and silver-bearing galena ores, sometimes containing rich silver minerals. Quartz is the commonest gangue mineral, but the beautiful pink rhodochrosite is also conspicuous.

The ore deposition is believed to be closely associated with the igneous intrusions of the district, especially with the later ones.

Most of the ore produced in the Rico district has been shipped crude or smelted in Rico without mechanical concentration.

Other Colorado Occurrences. — Argentiferous lead ores also occur in the Ten Mile district (6), in Chaffee County, and along the Eagle River (11). They are also known in Red Mountain.

Park City, Utah (1), which is located on the eastern slope of the Wasatch Range, about 25 miles southeast of Salt Lake City (Fig. 201), has made Summit County famous as one of the important mining centers of this country, as there are here large bodies of rich silver-lead ores carrying minor values of gold and copper. The success of this camp, therefore, depends more or less on the condition of the silver and copper industry.

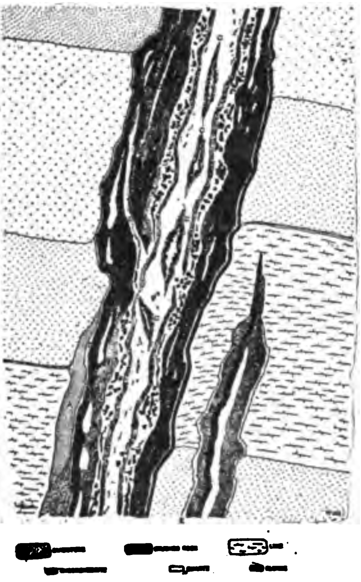

FIG. 194. — Vein filling a fault fissure, Enterprise mine, Rico, Col. (*After Rickard, Amer. Inst. Min. Engrs., Trans. XXVI.*)

The geological section involves a series of limestones, sandstones, and shales, chiefly of Carboniferous age, and having an aggregate thickness of over 6000 feet, with a general dip of 30 to 40 degrees northwest, and traversed by many fissures, faults, and intrusions, the last being of either dioritic or porphyritic types. The ores, which in the oxidized zone are cerussite, anglesite, azurite, malachite, etc., and in the sulphide zone are galena, tetrahedrite, and pyrite, occur either as lodes or fissures, or as bedded deposits in limestones. The latter, which supply most of the ore, form replacements in certain strata of both the Upper Carboniferous and Permocarboniferous, and lie between siliceous members as walls. Both types of ore deposit are frequently associated with porphyry.

The fissures carry either silver or lead with or without zinc, and copper or gold with some silver. The replacement ores of the limestones hold silver and lead chiefly. The contact ores contain copper and gold with or without silver, and form irregular bodies in metamorphic limestone adjacent to the igneous rock.

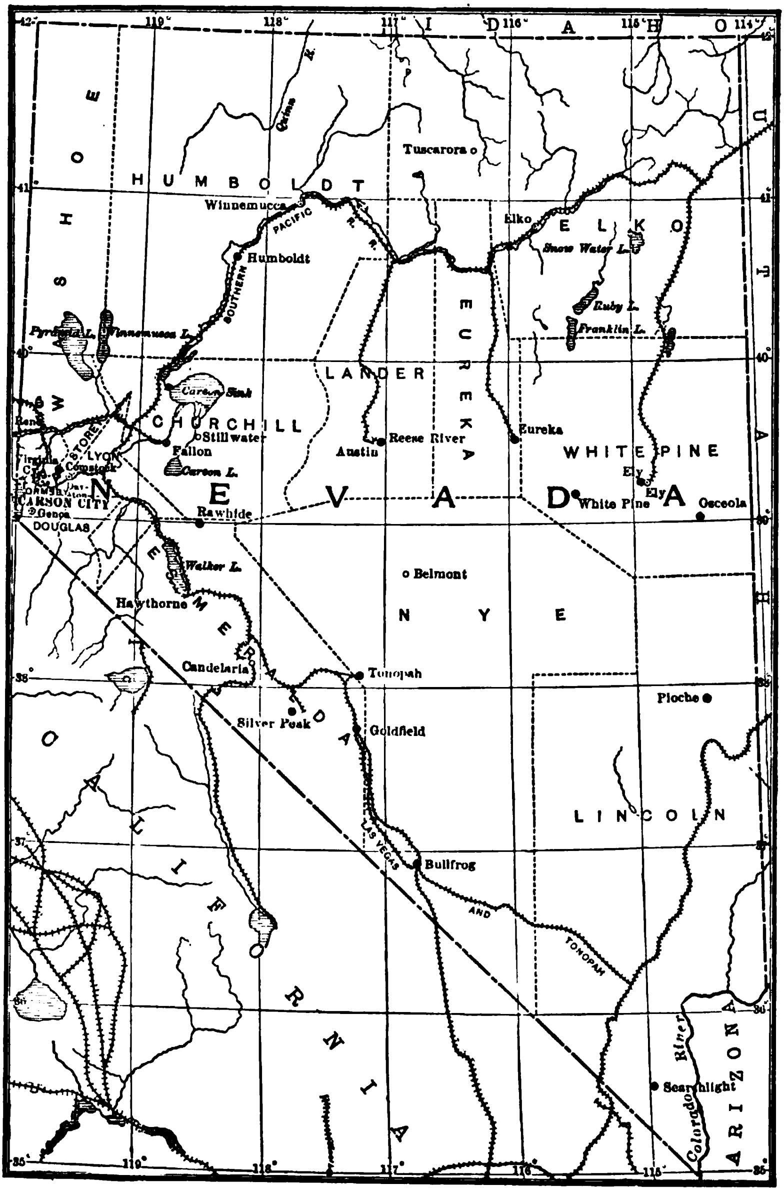

FIG. 195. — Map of Nevada, showing location of more important mining districts.

The ordinary crude ore carries 50 to 55 ounces silver, 20 per cent lead, .04 to .05 ounce gold, 1.5 per cent copper, 10 to 18 per cent zinc. Silver is obtained in the proportion of 3 ounces silver to each per cent iron, 1 ounce silver to each per cent lead, and .5 ounce silver to each per cent zinc. Bonanzas are known. The low-grade ores are treated at the concentrating mill, while the rich ores are shipped to the smelter.

Tintic District, Utah (16). — This district lies in the Tintic Mountains, about 65 miles southwest of Salt Lake City (Fig. 201). The ores are argentiferous galena, with a little copper, the average per ton of 240,000 tons being silver, 52.44 ounces; lead, 270 pounds; copper, 11.2 pounds; gold, .135 ounce.

The section of nearly 14,000 feet of folded Paleozoic sediments includes chiefly limestones, which after uplift and erosion were covered by Tertiary lavas and tuffs. The ores occur in zones in the limestones, as fissures in the igneous rocks, and along the contact. The minerals in the ore bodies are quartz, barite, pyrite, galena, sphalerite, enargite, silver and gold minerals and their oxidation products.

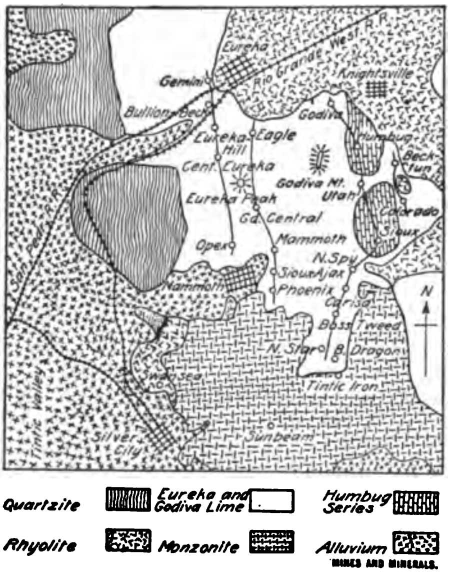

FIG. 196. — Geologic map of Tintic district, Utah. (*Adapted from Tower and Smith.*)

The Tintic is one of the oldest camps in the state, the ore having been discovered in 1869, and it was at first shipped as far as Baltimore and Wales. Since then mills have been erected at the mines. The chief towns are Eureka, Mammoth, Robinson, Silver City, and Diamond.

The same type of ore occurs in Big and Little Cottonwood cañons and Bingham Cañon (Fig. 201), the latter having been worked longer than those of the Tintic district. The camps lie southeast and southwest of Salt Lake City, and the ores are oxidized lead-silver ores, parallel to the bedding of Carboniferous limestones and the underlying quartzite. Galena and pyrite occur in the lower workings below water level.

PLATE XLV

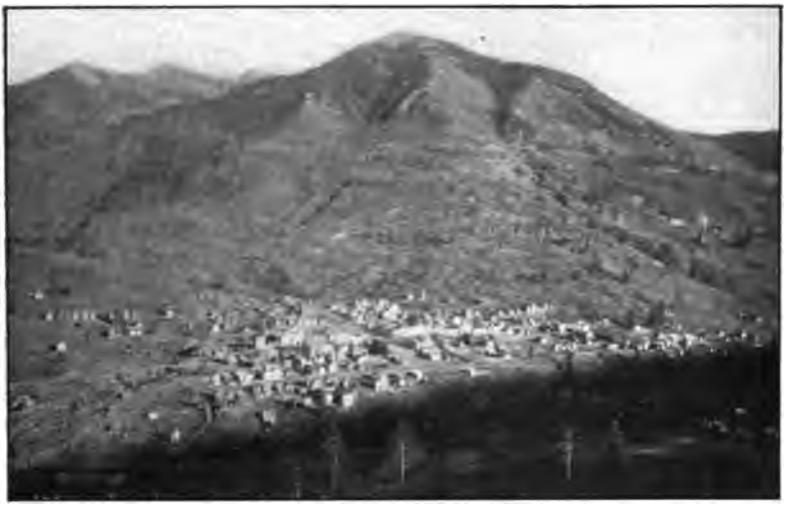

FIG. 1. — General view of Rico, Col., and Enterprise group of mines.

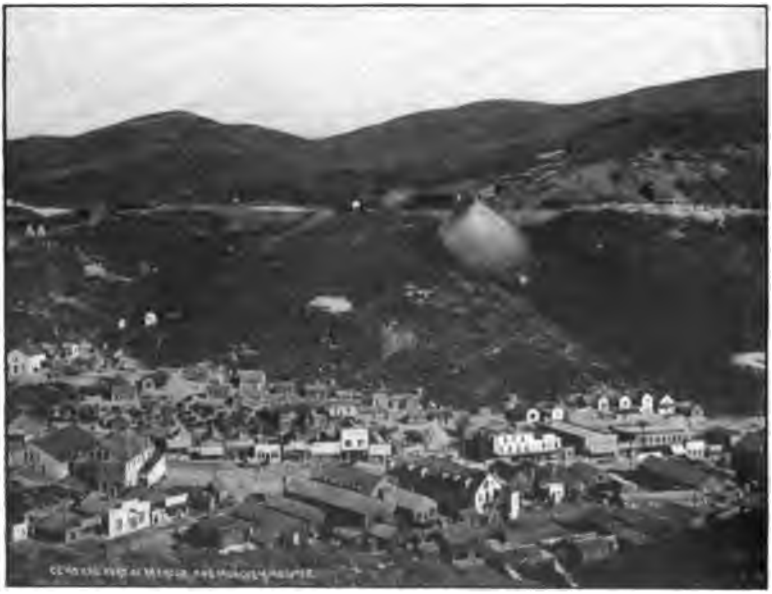

FIG. 2. — View of a portion of Mercur, Utah, and the Mercur mine.

Montana and Nevada, etc. — Montana contains several lead-silver ore localities. Those of Neihart (17) occur as veins in gneiss and igneous rocks, the ores being galena, silver sulphides, and some blende. The veins are best defined in the gneiss, and are mostly replacement deposits, which have been subsequently fractured and secondarily enriched. Lead-silver ores also occur at Glendale and in Jefferson County. Some are also known in South Dakota and New Mexico (2).

The Eureka district (8) of eastern Nevada (Fig. 195), discovered in 1868, is chiefly of historic importance. The ores are oxidized lead-silver ores, carrying some gold. They occur in Cambrian limestone which is much faulted and crushed, and is part of a Paleozoic section 30,000 feet thick.

The ore is associated with a great fault, and is oxidized to a depth of 1000 feet. There are two mining districts, Prospect Hill and Ruby Hill. Near the mines are great porphyry masses which are supposed to have afforded the ores. Up to 1882 the output was not far from $60,000,000 of precious metals and 225,000 tons of lead.

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CHAPTER XIX

GOLD AND SILVER

GOLD and silver are obtained from a variety of ores, in some of which the gold predominates, in others silver, while in still a third class these two metals may be mixed with the baser metals, lead, copper, zinc, and iron. Few gold ores are absolutely free from silver, and *vice versa,* so that a separate treatment of the two is more or less difficult; however, some lead-silver ores, although they may carry some gold, are sufficiently prominent to be discussed as a separate type, and have been referred to in the preceding chapter.

Ore Minerals of Gold. — Gold occurs in nature chiefly as native gold, mechanically mixed with pyrite, or as telluride such as calaverite ($AuTe_2$; Au, 39.5 per cent; Ag, 3.1 per cent; Te, 57.4 per cent).[1]

Gold is also found at times in chalcopyrite, arsenopyrite, and stibnite, but not as a rule in such large amounts as may be shown by pyrite. Sphalerite and pyrrhotite sometimes carry it.

The gold-bearing sulphides, as well as the tellurides, are all of primary character, although auriferous chalcopyrite might be formed by secondary enrichment.

Native gold may occur in the primary, secondary enrichment, or the oxidized zones. The tellurides, which are usually associated with pyrite, are quite widely distributed, but not always recognized; indeed by some they are mistaken for sulphides.

Ore Minerals of Silver. — The minerals which may serve as ores of silver, together with the percentage of silver they contain, are shown in the table on following page.

Galena, sphalerite, pyrite, chalcopyrite, and chalcocite may all be and frequently are argentiferous, but the silver in ore deposits is usually carried by galena.

Of the ore minerals above mentioned, the most common primary ones are argentiferous galena, sphalerite, and pyrite, while native silver and the sulphides and arsenides are less common.

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[1] Other tellurides are sylvanite and krennerite.

Mineral	Composition	Ag
Native silver	Ag	100.
Argentite, silver glance	Ag_2S	87.1
Pyrargyrite, ruby silver	$3 Ag_2S, Sb_2S_3$	59.9
Proustite, light ruby silver	$3 Ag_2S, As_2S_3$	65.5
Stephanite, brittle silver, black silver	$5 Ag_2S, Sb_2S_3$	68.5
Cerargyrite, horn silver	AgCl	75.3
Bromyrite	AgBr	57.4
Embolite	Ag(ClBr)	64.5
Iodyrite	AgI	46.
Tetrahedrite (Freibergite)	$4(Cu_2Ag_2FeZn)S, Sb_2S_3$	Variable; usually present; may be high.

In the oxidized zone, silver chloride is the most abundant, and native silver less so, while the iodides and bromides are quite rare and formed only under certain conditions.

The secondary enrichment ores include native silver, argentite, stephanite, tetrahedrite, pyrargyrite, and proustite. Argentiferous galena may also be present in the zone of secondary enrichment and be even richer in silver than the primary ore.

Mode of Occurrence. — Most of the gold and silver mined in the United States is obtained from fissure veins, or closely related deposits of irregular shape (112), in which the gold and silver ores have been deposited from solution, either in fissures or other cavities, or by replacement. Considerable gold and a little silver is obtained from gravel deposits, and some true contact-metamorphic deposits are known. Gold has been found to occur in rare instances as an original constituent of igneous rocks (1, 15, 18) and also metamorphic ones (19), but there are no known deposits of commercial value belonging to this type.

The gold- and silver-bearing fissure veins include two prominent types (112), viz.: (1) the quartz veins, and (2) the propylitic type, in which the metasomatic alteration of the wall rock is often propylitic, that is, accompanied by the formation of chlorite and epidote, but near the veins of sericite and kaolin. In the quartz-vein type silver is present usually in but small quantities, while in the propylitic type the silver often is an important constituent. Veins of intermediate character may also occur.

While the mode of occurrence of gold and silver is quite variable, the character of the wall rock is equally so, gold and silver ores being found in either sedimentary or igneous rocks, and along the contact between the two, showing that the kind of rock exerts little influence, except perhaps where replacement has been active. On the other hand the influence of locality is much stronger, for it has been found that many gold- and silver-bearing deposits are closely associated with masses of igneous rock, the most common of these being diorite, monzonite, quartz-monzonite, granodiorite, while true granites are rare as associates. A second large class of vein systems shows a close association with lavas of recent age, and the telluride ores rather favor these (8).

Weathering and Secondary Enrichment. — The superficial alteration of gold ores differs somewhat from that of deposits containing ores of the other metals. In quartz veins with auriferous pyrite, the change of the latter to limonite leaves a rusty quartz with nuggets or threads of free gold, and leaching may remove most of the iron. Some of the gold may also be leached out by the ferric sulphate, formed by the oxidation of the pyrite, and carried to lower levels, where it is reprecipitated. Ferric chloride in the presence of manganese oxide may also act as a solvent. Whether the reprecipitation of the gold is due to pyrite or carbonaceous matter is, in some cases at least, an unsettled question (6, and Ref. on ore deposits).

Telluride ores weather in a somewhat characteristic manner, the product being free gold. This may be of earthy appearance and faint brownish color, or consist of aggregates of extremely small crystals of gold which form a spongy mass, or a thin film on the surface of the rock.

Silver sulphides are changed to chlorides, and native silver may also be formed. In the weathered portion of some silver-bearing deposits, silver bromides and iodides are also found.

Penrose has suggested[1] that these ore bodies were in the vicinity of saline deposits, where haloid compounds were dissolved by the soil waters that penetrate the ores. Keyes, however, believes that the prevailing source of saline materials is the wind-blown dust produced by disintegrative processes so predominant in arid regions (9).

Geological Distribution. — Gold and silver ores have been deposited at a number of different periods in the geological history of the continent, notably, in the pre-Cambrian, Cambrian, Cretaceous, and Tertiary ages; but Silurian, Devonian, and Carboniferous gold deposits are not definitely known to exist in North

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[1] Jour. Geol., II: 1894.

America, although some of the Appalachian veins may be of this age (112). Silver ores show much the same geological range.

The geological distribution is referred to in more detail under Metallogenetic Epochs in Chapter XIV.

Classification. — A classification of gold and silver ores is in any event attended with more or less difficulty. Divisions based on geological and structural characters would for many purposes be more satisfactory, while for commercial or metallurgical work a grouping according to metallic contents is perhaps more desirable.

The following classification according to the associations of the ores is sometimes used (Lindgren).

1. Placers or gravel deposits. These serve chiefly as a source of native gold, but may, and often do, contain a little silver, much of which is never separated from the ore in which it occurs. These gravels are derived chiefly from quartz veins of Mesozoic age in the Pacific coast region, and to a less extent from pre-Cambrian veins of the Appalachian region and Black Hills of South Dakota. Some are also derived from veins in Tertiary lavas, but these usually contain the metals in such a finely divided condition, or in such combination, that they do not readily accumulate in stream channels.

2. Quartzose or dry ores, in which the gold and some silver are found in a quartz gangue, and are either free or mixed with sulphides, commonly pyrite. They are of varying age. Those of California, Oregon, and Alaska are Mesozoic and associated chiefly with quartz monzonite, granodiorite, and diorite. Another great class of post-Miocene age, found chiefly in Colorado, Nevada, and Montana, is associated with Tertiary lavas and characterized by bonanzas. The most productive ones carry fluorite and normally also tellurides. In some, gold may predominate; in others, silver. A third class, of pre-Cambrian age, is found in the Atlantic states, Wyoming, and South Dakota, the last mentioned including the famous Homestake mine. These are classified as dry ores, because they are not as a rule smelting ones; they contain limited quantities of copper and lead, but may have some pyrite.

3. Gold- and silver-bearing copper ores. These, which include ores with 2½ per cent or more of copper, are widely distributed throughout the United States, and exhibit great differences in form and age; neither do all the occurrences yield much gold or silver, and moreover they are of more importance as gold producers, silver being less often associated with the copper. The output is obtained chiefly from Colorado, Utah, and Montana. Those of the last two

states, which supply most of the production, are found as replacement veins in granites or early Tertiary igneous rocks. The large copper deposits of Arizona produce but little gold or silver, with the exception of those at Jerome. This class of ores yields about one third of all the silver mined in the United States.

4. Gold- and silver-bearing lead ores, containing 4½ or more per cent of lead. This class includes a variety of deposits, containing much lead, and also silver, with gold usually in subordinate amounts. They occur chiefly in Colorado, Utah, and Idaho, and furnish about one half of the silver obtained in the United States. They are discussed separately under the head of Silver-Lead ores.

A subtype of this class is represented by the veins of argentiferous galena and tetrahedrite of the Wood River district, Idaho. These are veins in slates near the contact of intrusive granite and are of late Mesozoic age. Arizona, California, Washington, and New Mexico produce small amounts of argentiferous lead ores.

5. Copper-lead or copper-lead-zinc ores. The former come mainly from the Park City and Tintic districts of Utah.

6. Zinc ores containing at least 25 per cent zinc. These yield but small amounts of either gold or silver. The zinc-lead ores produce more.

Extraction. — Since gold and silver ores vary so in their mineralogical associations and richness, the metallurgical processes involved in their extraction are varied and often complex.

Those ores whose precious metal contents can be readily extracted after crushing, by amalgamation with quicksilver, are termed *free-milling ores.* This includes the ores which carry native gold or silver, and often represent the oxidized portions of ore bodies. Others, containing the gold as telluride or containing sulphides of the metals, are known as *refractory ores* and require more complex treatment. These, after mining, are sent direct to the smelter if sufficiently rich, but if not they are often crushed and mechanically concentrated. The smelting process is also used for mixed ores, the latter being often smelted primarily for their lead or copper contents, from which the gold or silver is then separated. While in some cases there are smelters at the mines, still there is a growing tendency towards the centralization of the industry, and large smelters are now located at Denver, Salt Lake City, etc., which draw their ore supply from many mining districts.

Low-grade ores may first be roasted, and the gold then extracted by leaching with cyanide or chlorine solutions. The introduction of the cyanide and chlorination processes, which are applied chiefly to gold ores, has permitted the working of many deposits formerly looked upon as worthless, and in some regions even the mine dumps are now being worked over for their gold contents. It is estimated that in 1902 $8,000,000 worth of gold ores were cyanided. The chief fields are in the Cripple Creek region of Colorado; the De Lamar district, Idaho; Marysville, Montana; Bodie, California; and in Arizona.

The most important gold-milling centers of the United States are the Mother Lode district of California; the Black Hills, South Dakota; and Douglas Island, Alaska.

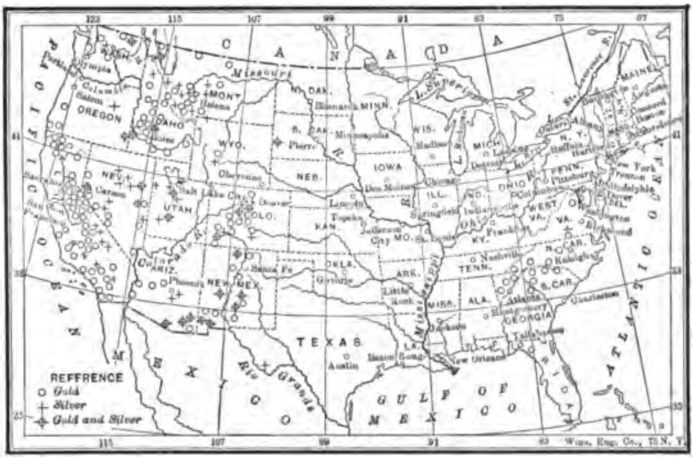

FIG. 197. — Map showing distribution of gold and silver ores in the United States. (*Adapted from Ransome, Min. Mag., X.*)

The value of ore and bullion is determined from a sample assay, and the smelter, in paying the miner for his ore, allows for gold in excess of $1 per ton of ore at the coining rate of $20.67 per ounce, and for silver at New York market price, deducting 5 per cent in each case for smelter losses. Lead and copper are paid for in the same manner, as are also iron and manganese, if there is a sufficient quantity present. No allowance is, however, made for zinc, and, in fact, a deduction is made if it exceeds a certain per cent.

Distribution of Gold and Silver Ores (Fig. 197). — Gold ores are widely distributed in the Cordilleran region and Appalachian province, while the silver ores are found chiefly between the Great Plains and Pacific coast ranges, exclusive of the Colorado plateau region. This occurrence in two widely separated areas is brought out in an interesting manner in Fig. 197.

More than a third of the United States production of gold comes from the southern half of the Rocky Mountains, Colorado being the main producer. In this area, however, the ores vary widely in their mineralogical associations, the gold occurring mostly in combination with silver, lead, copper, and zinc ores, but also at times free, or, in the most productive district, as a telluride.

The Pacific belt, excluding Alaska, supplies about 22 per cent of the total amount of gold produced, the famous Mother Lode region, mentioned later, being the most important producer. Alaska yields about 21 per cent, and the Basin Range province nearly 25 per cent, collected from widely separated deposits in Utah, Nevada, Arizona, and New Mexico, and in which the gold is associated with copper, silver, or lead.

Probably three fifths of the silver obtained in the United States comes from the Rocky Mountain region, Colorado alone yielding about one sixth, while Montana supplies about one fourth of the total amount produced, and about three fourths of this is obtained as a by-product in copper smelting. The Basin Range province furnishes something under two fifths, at least one half of this coming from Utah, especially from the Park City mines near Salt Lake City[1] (114).

The gold and silver occurrences of the United States and Alaska can be grouped under five areas, as follows: —

1. Cordilleran region.
2. Black Hills, South Dakota region.
3. Michigan region.
4. The Eastern Crystalline belt.
5. Alaska.

Of these, the first, second, and fifth are the most important, while the third is insignificant.

CORDILLERAN REGION

The area contains a number of important deposits of gold and silver ores, occurring chiefly in veins, and to a lesser extent in gravels.

These veins and associated deposits are divisible into three groups, based on their geologic age (112), viz.: (1) Cretaceous veins of the Pacific coast; (2) Late Cretaceous or early Tertiary deposits, sometimes referred to as the Central Belt; (3) Tertiary deposits.

Pacific Coast Cretaceous Gold-quartz Ores. — This important gold belt, which is characterized by quartzose ores with free gold and auriferous sulphides, extends along the Pacific coast from Lower California up to the British Columbia boundary. The deposits belonging to this are especially important in California, but farther

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[1] These estimates are, of course, only approximate.

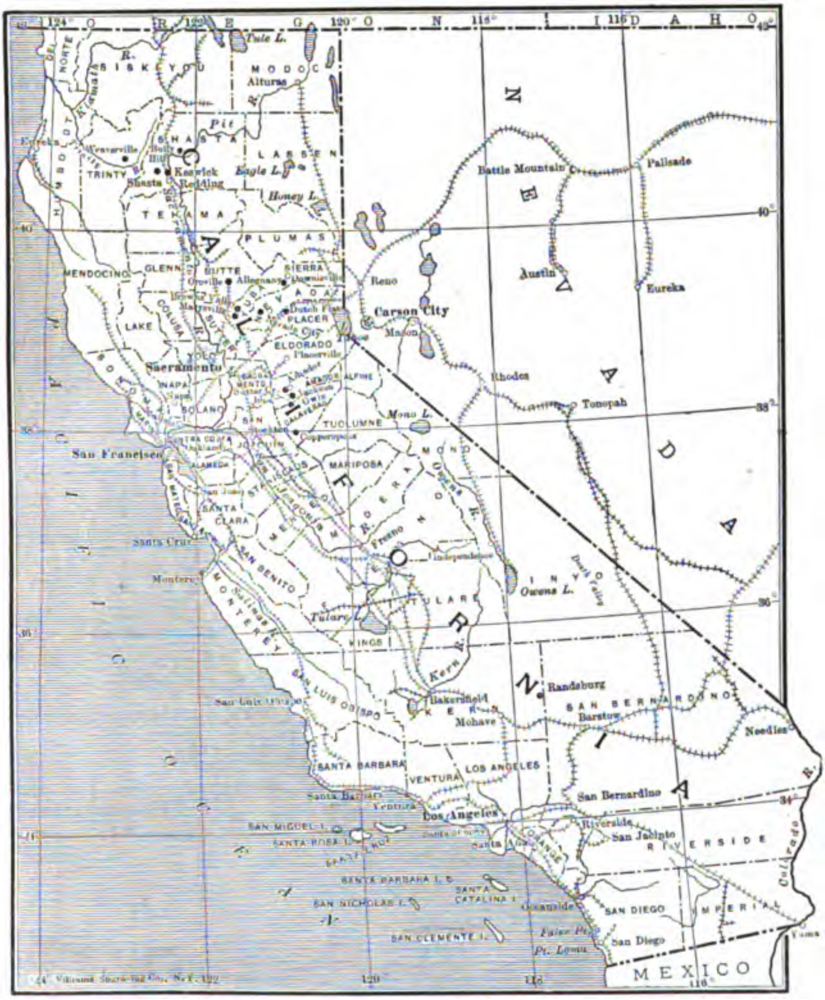

FIG. 198. — Map of California, showing location of more important mining districts.

north, in Oregon and Idaho, the veins in many cases have been covered up by the lava flows of the Cascade Range, and those known in that region differ somewhat from the California deposits in containing many mixed silver-gold ores and also veins carrying auriferous sulphides without free gold. The ores of this belt are all of undoubted Mesozoic age, and are accompanied by many extensive placer deposits, which have been derived by the weathering down of the upper parts of the quartz veins, the portions now remaining in the ground representing probably but the stump of originally extensive fissure veins (112).

Among the deposits of this belt two groups stand out in some prominence, namely, those of the so-called Mother Lode district and of Nevada County.

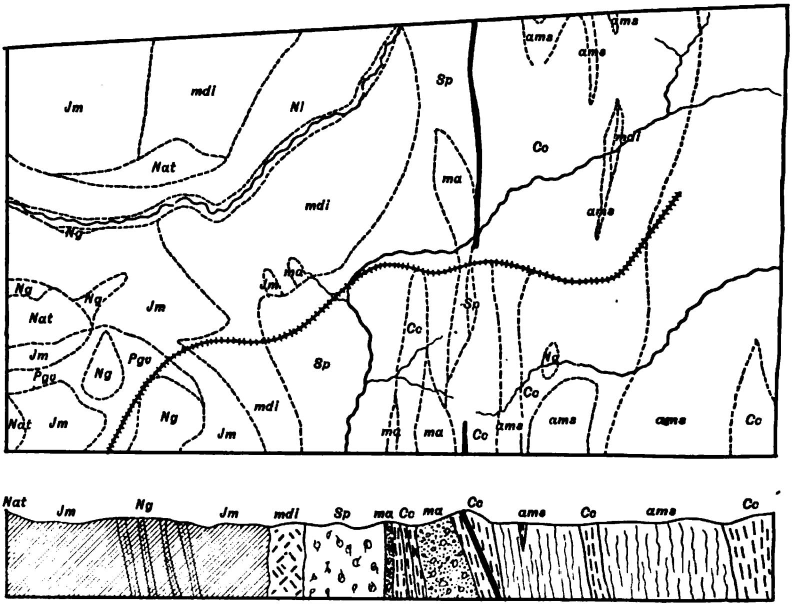

FIG. 199. — Map and section of portion of Mother Lode district, Calif. *Pgv*, river gravels, usually auriferous; *Ng*, auriferous river gravels. Sedimentary rocks: *Jm*, mariposa formation (clay, slate, sandstone, and conglomerate); *Cc*, calaveras formation (slaty mica schists). Igneous rocks: *Nl*, latite; *Nat*, andesite tuffs, breccia, and conglomerate; *mdi*, meta-diorite; *Sp*, serpentine; *ma*, meta-andesite; *ams*, amphibole schist. (*From U. S. Geol. Surv., Atlas Folio, Mother Lode sheet.*)

Mother Lode Belt. — This includes a great series of quartz veins, beginning in Mariposa County and extending northward for a distance of 112 miles. The veins of this system break through black, steeply dipping slates and altered volcanic rocks of Carboniferous and Jurassic age (Fig. 199), and since they are often found at a considerable distance from the granitic rocks of the Sierra Nevada, they have apparently no genetic relation with them. The veins,

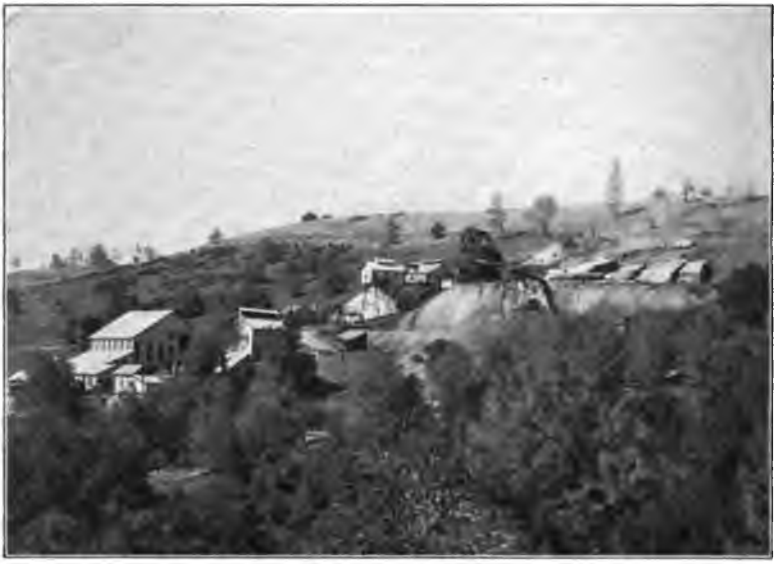

FIG. 1. — Kennedy mine on the Mother Lode, near Jackson, Calif.

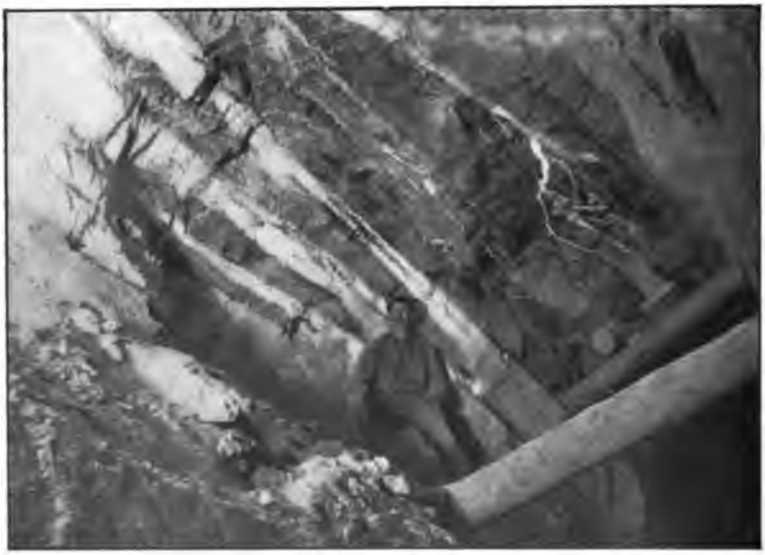

FIG. 2. — Auriferous quartz veins in Maryland mine, Nevada City, Calif. (*After Lindgren, U. S. Geol. Surv., 17th Ann. Rept., III.*)

which occur either in the slate itself or at its contact with diabase dikes, show a remarkable extent and uniformity, due to the fact that in the tilted layers of the slates there lay planes of weakness for the mineral-bearing solution to follow. The ore is native gold or auriferous pyrite in a gangue of quartz, and the average value may be said to vary from $3 to $4 up to $50 or $60 per ton. The veins often split and some of the mines have reached a depth of several thousand feet.

Nevada County (47). — In Nevada County the mines of Grass Valley and Nevada City are likewise quartz veins (Pl. XLVI, Fig. 2), but they occur along the contact between a granodiorite and diabase porphyry, as well as cutting across the igneous rock (Fig. 200). Two systems of fault fissures occur, and in these the ore is found

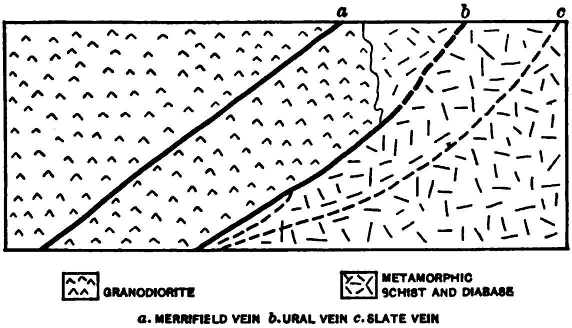
a
b
c
GRANODIORITE
METAMORPHIC SCHIST AND DIABASE
a. MERRIFIELD VEIN b. URAL VEIN c. SLATE VEIN

FIG. 200. — Section illustrating relations of auriferous quartz veins at Nevada City, Calif. (*After Lindgren, U. S. Geol. Surv., 17th Ann. Rept., II.*)

either in native form or associated with metallic sulphides. The width of the vein averages from 2 to 3 feet, and the lode ore generally occurs in well-defined bodies or pay shoots. The vein filling was deposited by hot solutions, and while the wall rocks contain the rare metals in a disseminated condition, Lindgren (47) believes that the ores have been leached out of the rocks at a considerable depth. The mines at Nevada City and Grass Valley have been large producers of gold and some silver. Placer mines have furnished a small portion of the product, but at the present day these latter are of little importance.

In Oregon, the quartz veins are worked in Baker County, which is the most important gold-producing region of the state (104, 105). Gold ores with sulphides in quartz gangue are worked in the Monte Cristo district of Washington (119).

Late Cretaceous or Early Tertiary Deposits. — The deposits of this age occupy a broad zone in the central and eastern part of the Cordilleran region, and are gold ores of varying character. While they differ in age and characters from the Pacific coast ores, and those of the belt to be next mentioned, nevertheless they are not absolutely separated from them geographically.

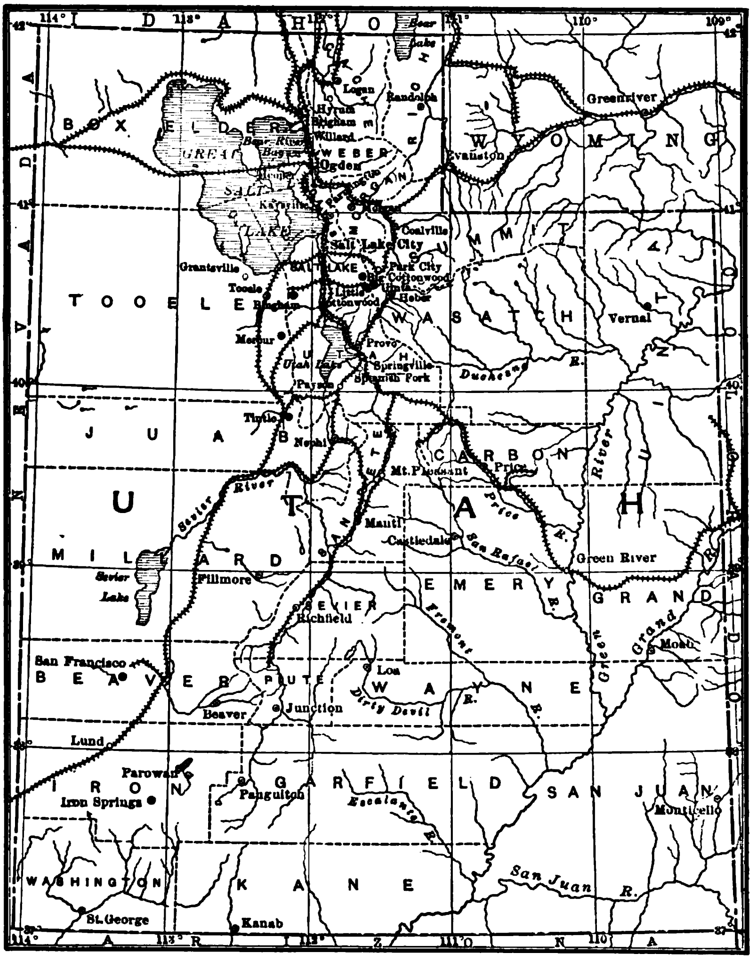

FIG. 201. — Map of Utah, showing location of more important mining districts.

The Mercur, Utah (Fig. 201), and Leadville, Colorado (Fig. 203), deposits, the latter referred to under lead and zinc, are included under this type.

Mercur, Utah. — The gold-silver mines of the Mercur (117) district in Utah form perhaps the most important occurrence in this central zone. Here the Carboniferous limestones, shales, and sandstones, representing about 12,000 feet of sediments, are folded into a low anticline (Fig. 202). Near the center of the section is the great blue limestone, carrying an upper and a lower shale bed. Quartz porphyry has intruded the limestone, and, at two places especially, spread out laterally in the form of sheets, on whose under side the ore is found, the silver ores under the lower sheet, the gold ores under the upper one, about 100 feet above the first. The silver ore is cerargyrite and argentiferous stibnite in a silicified belt of the limestone. The gold is native and occurs in a belt of residual contact clay, near northeast fissures cutting the limestone, being oxidized in places and accompanied by sulphides in others.

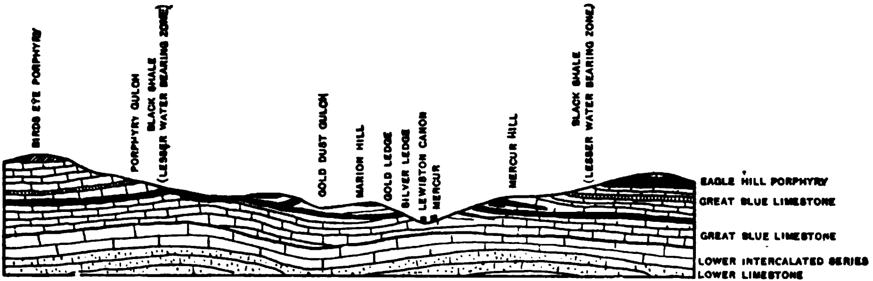

FIG. 202. — Section at Mercur, Utah. (*After Spurr, U. S. Geol. Surv.*, 16*th Ann. Rept.*, *II.*)

The ore runs 1–19 ounces of silver per ton, and 2–3 ounces of gold, with a gangue of quartz, barite, limonite, and arsenical sulphides. The silver minerals are thought to have been deposited by heated solutions which came up along the igneous sheet some time after its intrusion, and the deposition of the gold ore is believed to have taken place some time after the silver was deposited. Some doubt exists as to the exact source of the ascending waters, but in all probability they were derived from some deep-seated cooling laccolith. The ores are especially suited to the cyanide treatment.

Other Occurrences. — The northward continuation of this belt of gold-bearing veins in Idaho and Montana presents somewhat different types of deposits, for there the veins are causally connected with great batholiths of Mesozoic granite; and while the veins resemble those of the Pacific coast in the quartz filling and free gold contents, they differ from the latter in containing more silver, and often large quantities of sulphides with little free gold. In fact in their geologic relations they are intermediate between the quartz vein and propylitic type. Of special prominence are those of Marysville, Montana (80), and Idaho Basin, Florence, etc., in Idaho. This difference is more marked in the Montana occurrences, in which the gold becomes subordinate and is obtained as a by-product in silver mining.

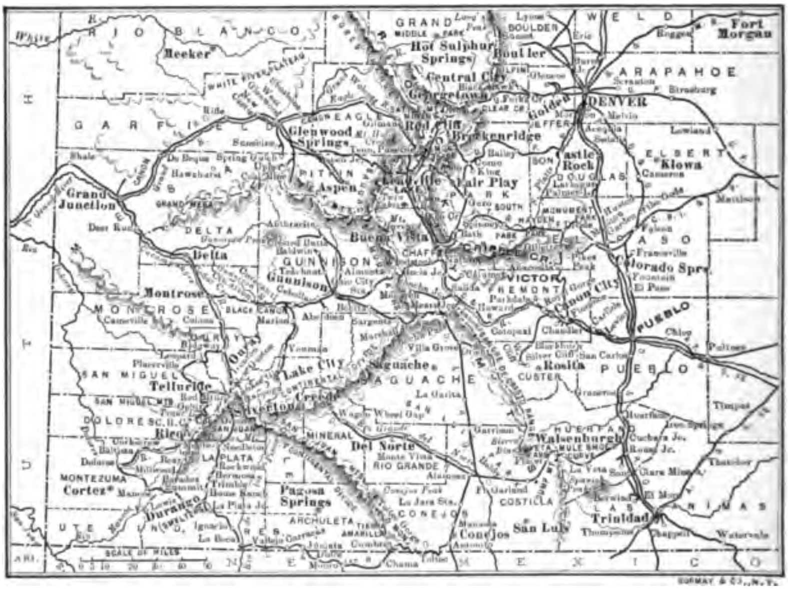

FIG. 203. — Map of Colorado, showing location of mining regions. (*After Rickard, Amer. Inst. Min. Engrs. Trans.*, 1904.)

Eastern Belt of Tertiary Gold-Silver Veins. — Of greater importance than the preceding class are the veins of Tertiary, mostly post-Miocene, age, which, according to Lindgren, are characteristic of regions of intense volcanic activity, and cut across andesite flows, or more rarely rhyolite and basalt. The veins may be entirely within the volcanic rocks, or the fissures may continue downward into the underlying rocks, which have been covered by the extrusive masses. Many of these Tertiary deposits belong to the propylitic class, showing characteristic alterations of the wall rock. The ores are commonly quartzose, and though either gold or silver may predominate, the quantities of the two metals are apt to be equal. Bonanzas are of common occurrence, and on this account the mines

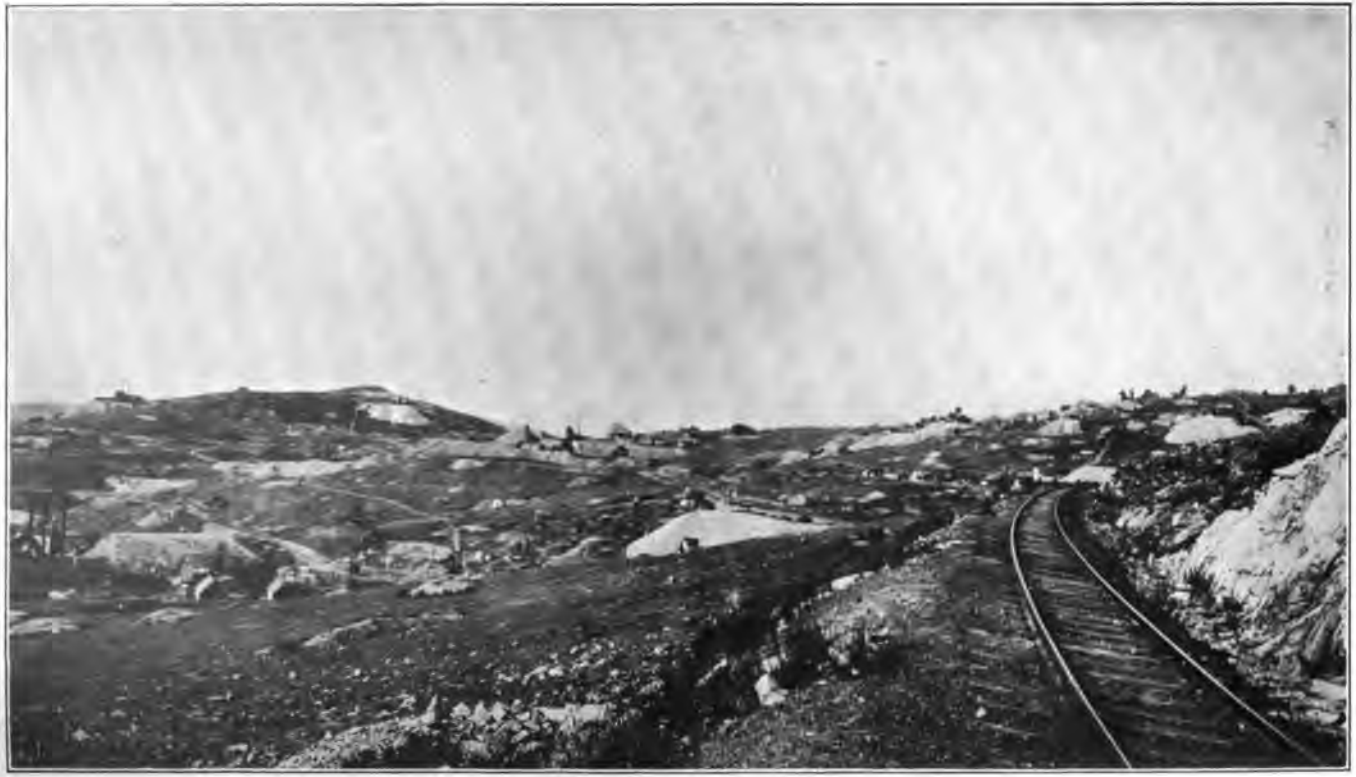

Plate XLVII. — General view in Cripple Creek district. The outcrop on right is phonolite. (*H. Ries, photo.*)

may be very rich but short-lived; still, the workable ore in many extends to great depths, but is less rich than nearer the surface. Extensive and rich placers are rarely found in the Tertiary belt of veins, for the reason that the fine distribution of the gold is not favorable to its concentration and retention in stream channels. Deposits of this type are worked in a number of states, including Colorado, Nevada, Arizona, New Mexico, and Idaho. Colorado leads in the production of gold ores, for in no state are the Tertiary deposits of the propylitic type developed on such a scale.

Several of the more important representatives of this type may be mentioned.

Cripple Creek (63). — This district, which is a most important one in this belt, is a producer of ores containing gold almost exclusively. The region lies about ten miles west of Pikes Peak proper, but in the foothills of this mountain mass.

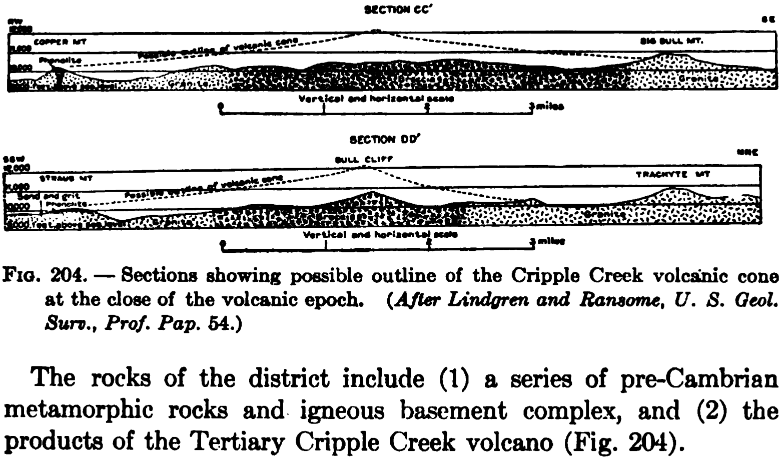

FIG. 204. — Sections showing possible outline of the Cripple Creek volcanic cone at the close of the volcanic epoch. (*After Lindgren and Ransome, U. S. Geol. Surv., Prof. Pap.* 54.)

The rocks of the district include (1) a series of pre-Cambrian metamorphic rocks and igneous basement complex, and (2) the products of the Tertiary Cripple Creek volcano (Fig. 204).

The metamorphic rocks include a quartz-muscovite-fibrolite schist, and a biotite gneiss; the old igneous rocks include (1) three varieties of granite, viz. the Pikes Peak (quartz-biotite-microcline), Cripple Creek (finer-grained but similar), Spring Creek (quartz-orthoclase mainly, and of medium grain); and (2) differentiation products of an olivine-syenite magma.

The Tertiary volcanic rocks represent a series of chemically related products, from a single eruptive center. Commonest of these are tuffs and breccias, which are cut by a series of dikes of phonolite, next a latite-phonolite, followed by a syenite, trachydolerite, and several dark basic dike rocks.

The ore bodies, which in nearly all cases are associated with fissures, are of two types, viz. (1) lodes or veins (Figs. 205, 206), and (2) irregular replacement bodies, occurring usually in granite. The two are not sharply separated.

All the veins are characterized by the narrowness of the fissure and incomplete filling. The lode fissures occur mainly within the volcanic neck, have a roughly radial plan, and are usually nearly vertical, the individual fissures rarely exceeding a half mile in length. But even the productive ones may be quite short, not exceeding a few hundred feet; and while productive lodes may occur in all rocks, except perhaps the schist, they seem to favor the breccia and granite, many following phonolitic or basic dikes.

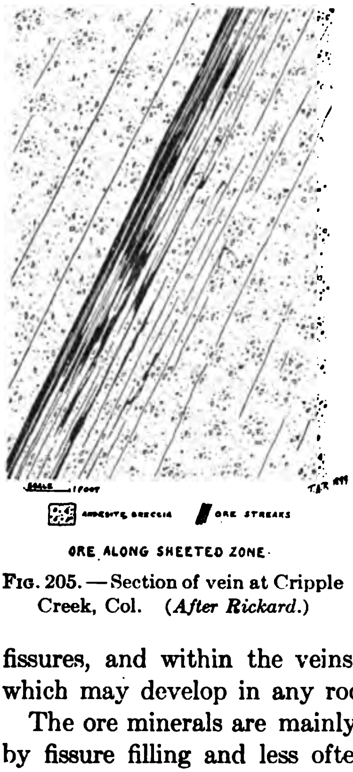

FIG. 205. — Section of vein at Cripple Creek, Col. (*After Rickard.*)

The lodes generally show a characteristic sheeted structure, but the fissures in general are not fault planes, having probably been formed about the same time as the intrusions of the basic dikes and caused by compressive stresses set up by a slight sinking of the solidified breccia and associated intrusives.

The ore occurs filling narrow fissures, and within the veins it occurs in shoots of variable size, which may develop in any rock.

The ore minerals are mainly tellurides of gold, deposited mainly by fissure filling and less often by replacement, with pyrite as a common associate; but native gold is rare in the unoxidized ore. Quartz, fluorite, and dolomite are the most important gangue minerals, and galena, sphalerite, tetrahedrite, stibnite, and molybdenite are found sparingly.

Oxidation changes the vein to a soft brown, homogeneous mass, and the tellurides into brown, spongy gold and tellurites, but there is no evidence of secondary enrichment. The ore does not appear to decrease in its value per ton with depth, though the actual quantity of it is less.

The rocks bordering the veins have undergone some alteration, which is more pronounced in the breccia, and involves a change of the dark silicates to carbonates, pyrite, and fluorite, and of the feldspars and feldspathoids to sericite and adularia.

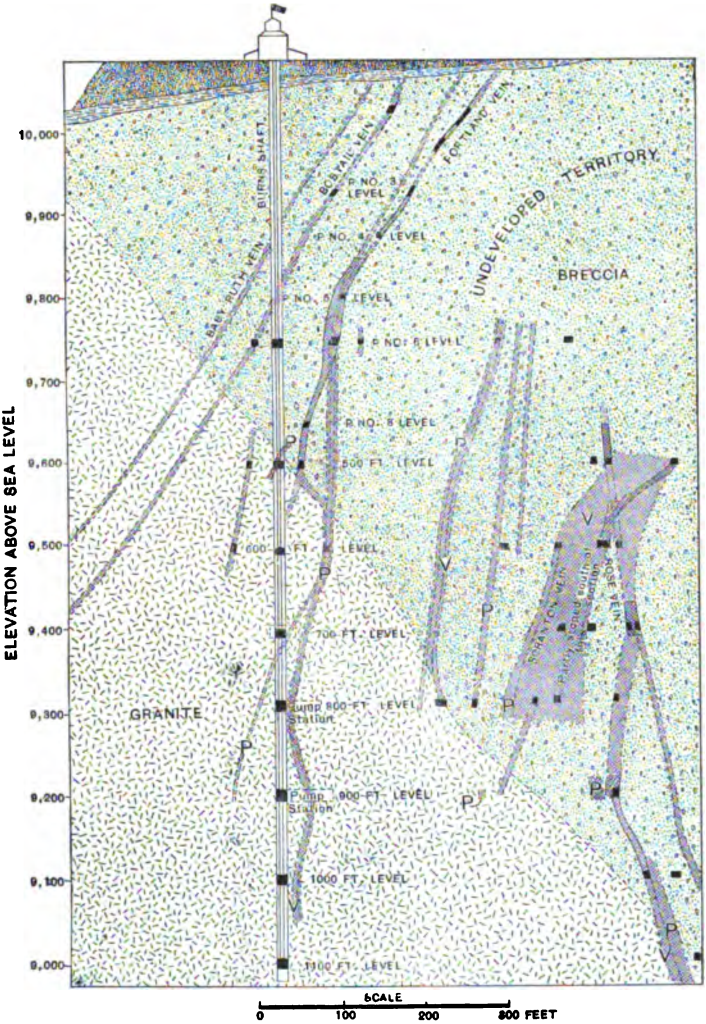

FIG. 206. — Vertical section through the Burns shaft, Portland Mine, Cripple Creek, Col. Shows breccia, contact veins, and dikes. *V*, veins; *P*, phonolite. (*After Lindgren and Ransome, U. S. Geol. Surv., Prof. Pap.* 54.)

The ores are believed to have been deposited by hot alkaline solutions, which contained the following compounds and ions either free or in combination: SiO_2, CO_2, H_2S, CO_3, SO_4, S, Cl, F, Fe, Sb, Mo, V, W, Te, Au, Ag, Cu, Zn, Pb, Ba, Sr, Ca, Mg, Na, K. Some of these may have been leached out of the volcanics.

The ore is in part smelting ore, which is sent to Pueblo and Denver for treatment, but the balance, which is considerable, is treated by the cyanide or the chlorination process.

The Cripple Creek ores as a rule run low in silver and from 1 to 10 ounces of gold per ton, with an average value of $30 to $40 per ton. Most of the ores are treated by the chlorination or cyanide process, especially the former, and about one sixth of the output is shipped directly to the smelters at Denver and Pueblo.

The rapid rise of this district is well shown by the following figures of production. A maximum was reached in 1900, since which the output has gradually declined.

PRODUCTION IN CRIPPLE CREEK DISTRICT IN 1893–1908

YEAR	VALUE	YEAR	VALUE
1893	$2,010,367	1902	$16,912,783
1894	2,908,702	1903	12,967,338
1895	6,879,137	1904	14,504,350
1896	7,512,911	1905	15,441,591
1897	10,139,708	1906	14,286,675
1898	13,507,244	1907	10,953,549
1899	15,658,254	1908	12,772,477
1900	18,073,539	Total	$191,790,204
1901	17,261,579		

San Juan Region, Colorado (59, 62, 65, 66, 67). — This region covers a large tract of mountainous country, in southwestern Colorado, and includes the counties of San Juan, Dolores, La Plata, Hinsdale, and Ouray. The continental divide crosses it, but the main portion consists of a deeply cut volcanic plateau. The area is an important one noted for its veins carrying gold, silver, and lead ores in varying proportions, but owing to the precipitous slopes, high ridges, and great altitude at which the veins outcrop, mining is sometimes attended with difficulty. Important towns in the area are Telluride, Silverton, Ouray, Creede, etc.

The geological history of the San Juan region is exceedingly complex, the pre-Tertiary surface being deeply buried under volcanic beds which still cover the main area, but the older rocks have been exposed by erosion in the surrounding districts. The most complete section is seen in the Animas Valley, between Silverton and Durango, but the two generalized columnar sections of the Telluride and Ouray quadrangle (Pl. XLIX) will serve to give a somewhat clear idea of the age and succession of the formations.

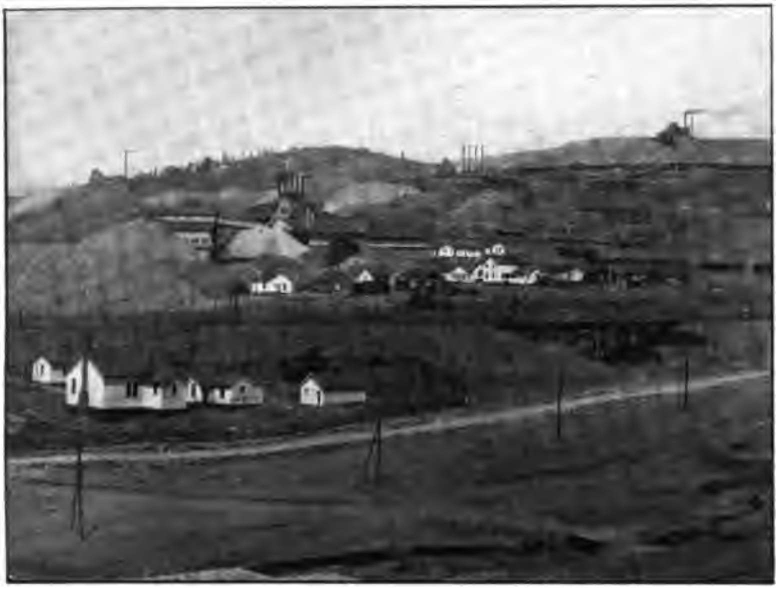

FIG. 1. — View of Independence Mine and Battle Mountain, Cripple Creek, Col. (*A. J. Harlan, photo.*)

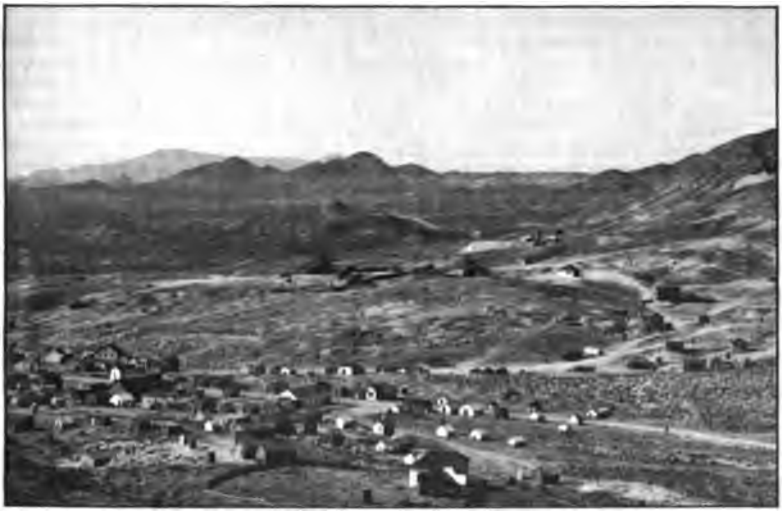

FIG. 2. — General view of region around Tonopah, Nev. (*J. E. Spurr, photo.*)

The entire region has not been studied in detail geologically, but several quadrangles are known with some intimacy and may be referred to.

Telluride Quadrangle (65). — In this quadrangle whose geologic section is shown (Pl. XLIX and Fig. 207) the ores occur in veins which are filled fissures that penetrate all rocks exposed in the area, and were later even than the rhyolite or the intrusions of the diorite stocks. Four general directions of fissuring are noted.

The lodes are narrow zones of closely spaced fissures filled with ore, little of which is found outside of the zone. The veins vary in width, averaging about 3 feet, but the ore usually forms a narrow strip following one side or the other, and rarely filling the entire zone.

The veins also vary somewhat in their regularity, according to the kind of rock through which they pass, being best developed in the andesite. Faulting is rare.

The ore minerals are galena, freibergite (argentiferous gray copper), polybasite, proustite, stephanite, and perhaps other silver sulphides, with more or less gold, which may be in pyrite and chalcopyrite. There are also a number of metallic and non-metallic gangue minerals, including sphalerite, zinc blende, mispickel, magnetite, native copper, quartz, calcite, siderite, rhodochrosite, dolomite, fluorite, barite sericite, biotite, chlorite, amphibole, apatite, garnet, orthoclase, picotite, and kaolinite.

The greater number of veins have been found in the granular rocks of the stocks along the central, east, and west portions of the area, and in the heavy andesitic breccia, tuff, and agglomerate of the San Juan formation (Pl. XLIX), best developed

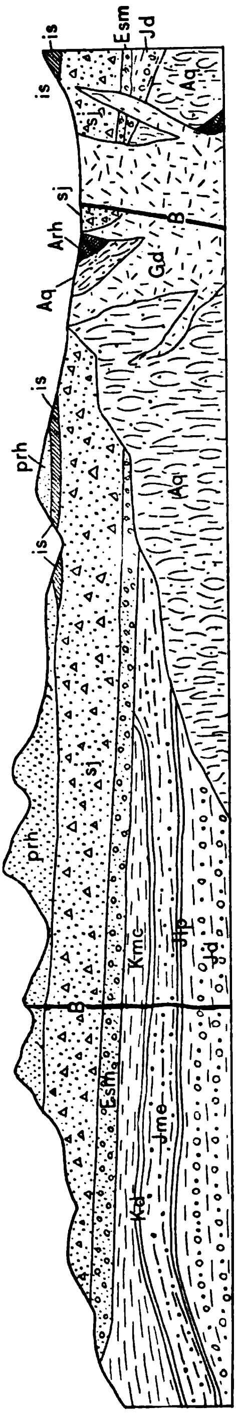

FIG. 207. — Geologic section across the northwest portion of the Telluride quadrangle. (*U. S. Geol. Surv.*)

in the northern half of the area. This last horizon has been the most productive.

The ore appears to have been deposited from ascending hot-water solutions which penetrated all open spaces in the fissured zones.

Ransome explains it as follows: Surface waters percolating downward dissolve alkalies from the igneous rocks as sulphides. These alkalies as they become hotter on approaching the magma become charged with sulphidic and carbonic acids derived from volcanic sources, thus becoming solvents for the metals, and silica, lime, etc., which they gathered from the more basic portions of the magma. These solutions then brought metals and silicates and deposited them higher up.

The metals were deposited in the fissures, while the penetration of the wall rocks by the alkaline solutions containing sulphuric acid changed the iron in the ferromagnesian silicates, and the potash went towards the formation of sericite. Carbonates were deposited on the walls, due to action of water on lime feldspars. Silica was set free and removed mostly from the walls. Gold was carried into the walls to some extent.

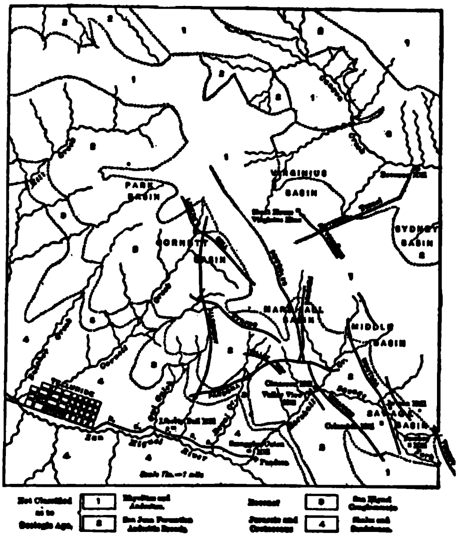

FIG. 208. — Geologic map of Telluride district, Col., showing outcrop of more important veins. (*After Winslow, Amer. Inst. Min. Engrs., Trans. XXIX.*)

Silverton Quadrangle (67). — This quadrangle lies east of the Telluride. The oldest formations are the Archæan schists and gneisses, overlain by Algonkian quartzites, and these in turn by Cambrian, Devonian, and Carboniferous sediments, the whole being capped by a thick series of Tertiary volcanics similar to those of the Telluride quadrangle, but separated from the top of the Carboniferous by a conglomerate. A number of unconformities are present in different parts of the series.

The ore deposits are of three types, viz.: (1) lodes, which include most of the now productive deposits; (2) stocks or masses, which

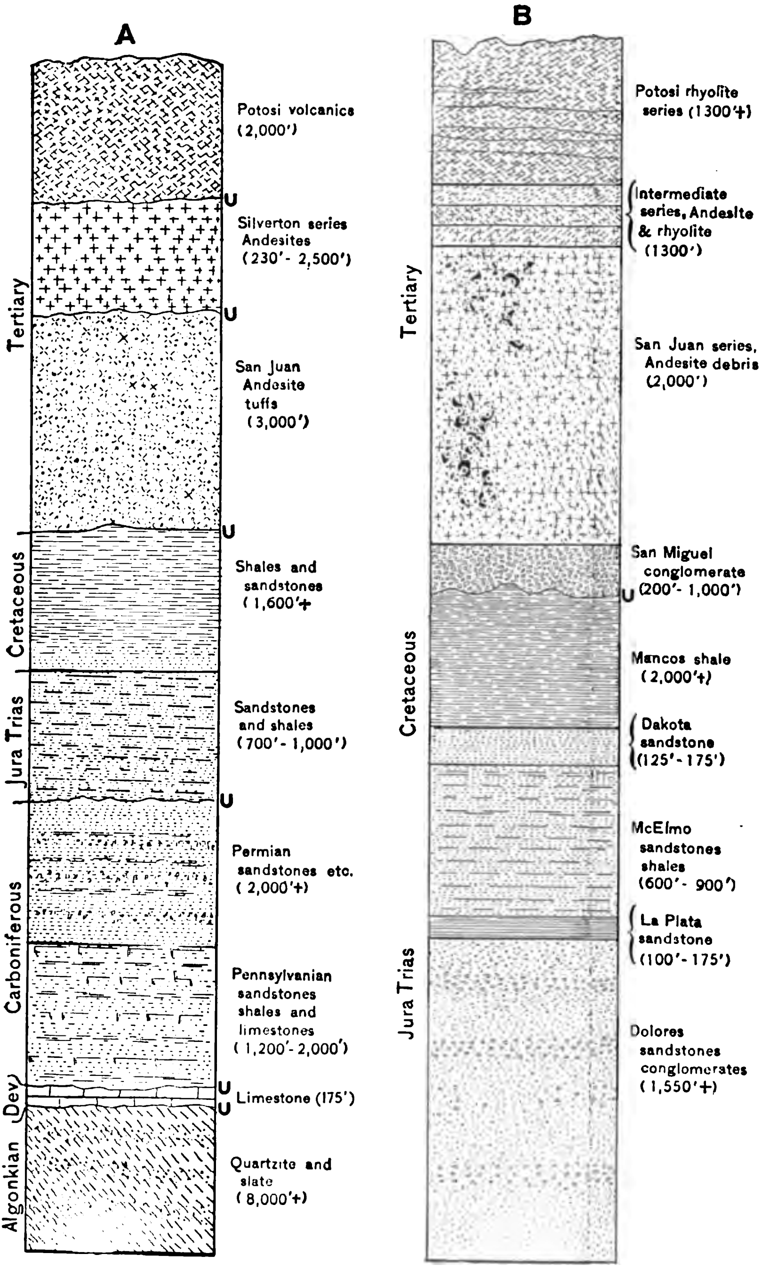
A
Potosi volcanics (2,000')
U
Silverton series Andesites (230'- 2,500')
U
San Juan Andesite tuffs (3,000')
U
Shales and sandstones (1,600'+
Sandstones and shales (700'- 1,000')
U
Permian sandstones etc. (2,000'+)
Pennsylvanian sandstones shales and limestones (1,200'- 2,000')
U
Limestone (175')
U
Quartzite and slate (8,000'+)
Tertiary
Cretaceous
Jura Trias
Carboniferous
Dev
Algonkian
B
Potosi rhyolite series (1300'+)
Intermediate series, Andesite & rhyolite (1300')
San Juan series, Andesite debris (2,000')
San Miguel conglomerate (200'- 1,000')
U
Mancos shale (2,000'+)
Dakota sandstone (125'- 175')
McElmo sandstones shales (600'- 900')
La Plata sandstone (100'- 175')
Dolores sandstones conglomerates (1,550'+)
Tertiary
Cretaceous
Jura Trias

PLATE XLIX.—General columnar section of *A*, Ouray quadrangle; *B*, Telluride quadrangle. U = unconformity. (*U. S. Geol. Surv.*)

include most of the ore bodies formerly worked on Red Mountain; (3) metasomatic replacements, including a few deposits found in limestones or rhyolite.

The lodes, which are widely distributed and vary in size and degree of mineralization, may occur in all the rocks from the pre-Cambrian schists to the latest monzonitic intrusions, cutting the Tertiary volcanics, but the greater number are found in the San Juan tuff and Silverton volcanic series. Moreover, the gold and silver are not uniformly distributed in the quadrangle.

The most conspicuous fissuring is northeast-southwest, with dips usually of about 75°, and faulting noticeable in but a few lodes. The fissures were formed substantially at the same time, and probably in late Tertiary.

Most of the lodes are simple fissure veins, showing bands of gangue and ore confined between definite walls, while the width of the workable vein varies from a few inches up to 10 or 12 feet. The wall rock is not usually much altered except in the rhyolite replacement deposits.

The ore minerals are tetrahedrite, very common, may carry both As and Sb; enargite, common in Red Mountain range; chalcopyrite, common and sometimes auriferous; galena, very important and widespread; sphalerite, common and accompanies galena, and several silver sulphides, not very abundant. Both native gold and silver also occur.

The gangue minerals are quartz, barite, calcite, dolomite, rhodochrosite, kaolinite, pyrite, etc.

The ores were probably deposited by ascending waters, but their exact source or depth of origin is not known.

Metasomatism of wall rocks differs in different parts of the quadrangle. Thus, for example, in the Silver Lake Basin, feldspar is altered to sericite, calcite, and quartz; augite, to calcite and chlorite; and biotite, to sericite and rutile. Sericite and quartz are common close to the vein. This shows a propylitic type of alteration.

Ouray Quadrangle (62). — The ore deposits, which may be regarded as an extension of those of the Silverton quadrangle area, are all located near the town of Ouray, and while the district contains but few productive mines, they are of great scientific interest. A few are found in disturbed rocks near dikes or sheets of porphyry, but most of them occur in but slightly disturbed formations. All owe their existence to the presence of fissures, the form of the ore body depending, however, on the openness of the fissure and kind of wall rock. The three following types are recognized: (1) fissure veins of great vertical extent; (2) replacements in quartzite; (3) replacements in limestone. Where the fissures followed by the ore-bearing solutions were open, a simple, banded, filled vein was formed; but where narrow, the solutions spread out laterally in the wall rock, replacing the same, and the process reached a maximum in the more soluble beds.

The fissures show great vertical extent, and the characters of the several types are as follows:—

Fissure Veins.—(*a*) This type, which is the most important, includes silver-bearing veins in fissures of slight displacement, distributed from the Mancos shale, to the sandstones underlying the McElmo (Pl. XLIX). Ore more abundant and of higher grade in quartzite walls, but may be absent or of low grade in shales. Tetrahedrite and argentiferous galena, with quartz and barite, gangue as common vein mineral. (*b*) Gold-bearing veins, representing a group of mineralized, highly inclined, sheeted zones in dikes of quartz-bearing monzonite porphyry. The chief minerals are auriferous pyrite, and chalcopyrite in a gangue of country rock and clay.

Quartzite Replacements.—Irregular bodies in the Dakota sandstones, with gold and subordinate silver.

Limestone Replacements.—Broad flat ore bodies, adjoining fissure veins, or associated with numerous small vertical fissures. Silver predominates in some, with a barite, silica gangue, and gold with a magnetite gangue in others. The former are associated with the fissure veins which penetrate limestone.

All the deposits of the Ouray district appear to belong to a single period of mineralization, and are of recent formation, being later than the latest igneous intrusions.

Georgetown, Colorado (68).—Clear Creek County (Fig. 209), in which Georgetown lies, is, next to Gilpin County, the oldest mining district in Colorado, if not the entire Rocky Mountain region.

There are a number of mining camps in this area, including Georgetown, Idaho Springs, Silver Plume, Central City, etc., but the only area which has been recently described is that included in the Georgetown quadrangle. The conditions here, however, are in a general way similar to those existing in other parts of the district.

The earliest rocks of the district consist of a series of pre-Cambrian schists, the oldest ones (Idaho Springs formation) being probably

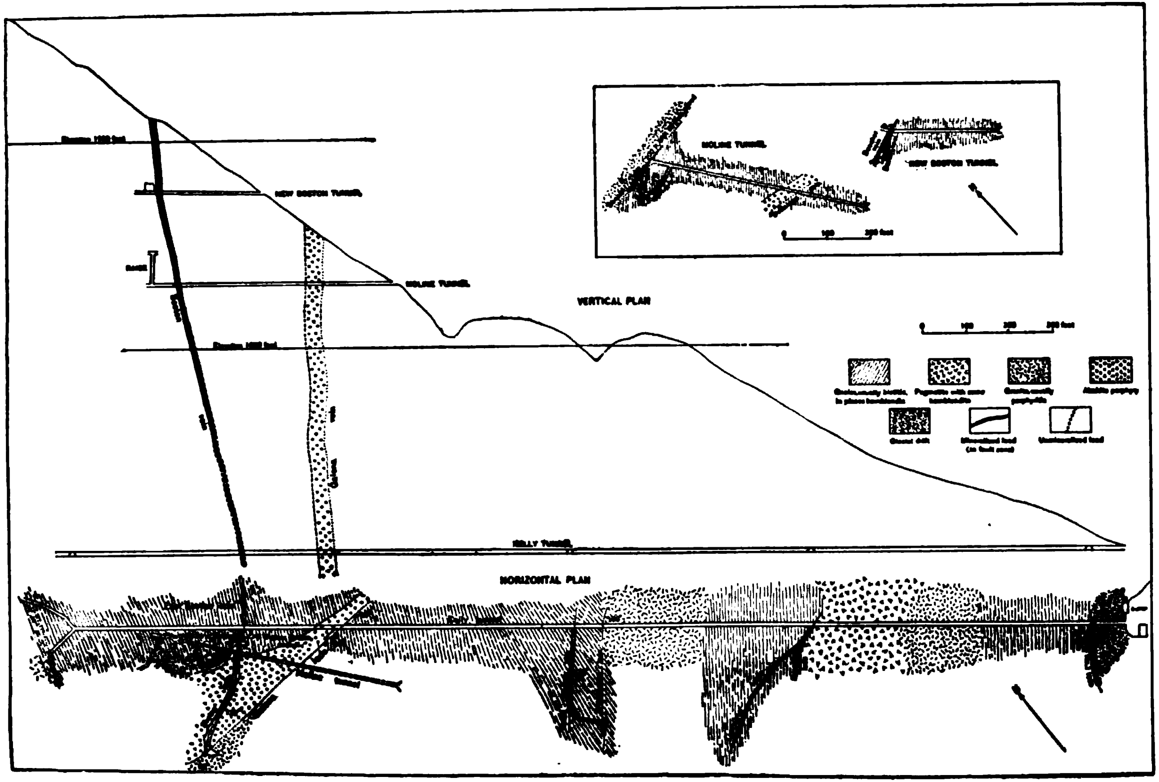

Plate L. — Vertical and horizontal plan of Kelly tunnel and associated mine workings, Georgetown, Col., district. (*After Spurr, U. S. Geol. Surv., Prof. Pap.* 63.)

of sedimentary origin, but the later ones metamorphosed igneous rocks.

This series has been successively injected by about eight types of plutonic rocks ranging from granites to diorites.

Following these, in late Cretaceous or early Tertiary, came the intrusion of a series of porphyry dikes which are as varied in their compositon as the plutonics. These porphyries are of more than local interest because they form part of a wide irregular zone that extends in a general northeast-southwest direction from Boulder to Leadville and then on to the San Juan region (Fig. 209). It will thus be seen that many important mining districts lie within it.

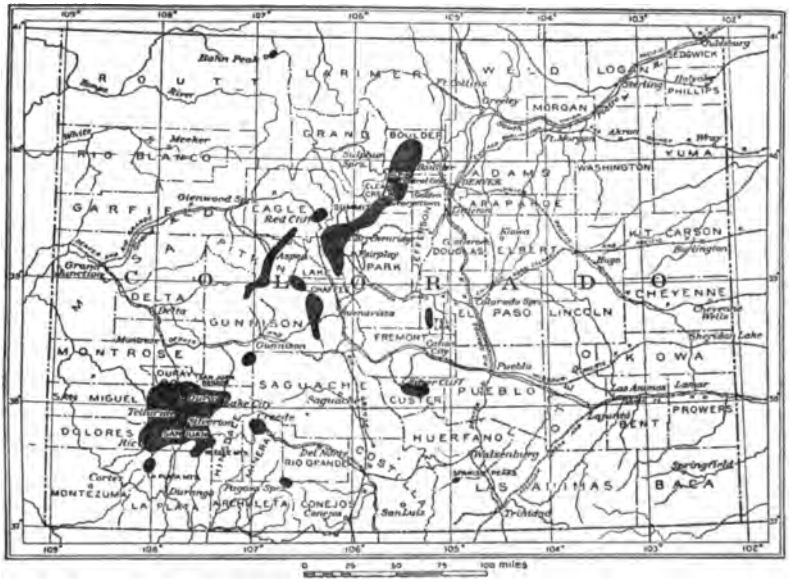

Fig. 209. — Map showing approximate distribution of principal silver, lead, and gold regions of Colorado. (*After Spurr, U. S. Geol. Surv., Prof. Pap.* 63.)

The ore-bearing fissure veins (Pl. L) which may occur in any of the older schistose rocks of the district, are divisible into two groups, viz. argentiferous blende-galena ones with little gold, and auriferous pyrite veins with or without silver. The former predominate in the Georgetown region, the latter southwest of Idaho Springs, but the two types of ore are occasionally known to occur in the same vein. Both types of veins are seen to show a general agreement in trend and distribution with the porphyry dikes (Pl. LI), and the vein formation is thought by Spurr not only to have followed the porphyry intrusions, but to show characteristic petrographic associations. That is, the silver-galena-blende veins are related to dikes of alaskite porphyry, granite porphyry, quartz-monzonite porphyry, and dacite; the auriferous pyrite veins with bostonite, alaskite, quartz monzonite, biotite latite, and alkali syenite.

The two classes of veins show the same primary minerals (galena, blende, and pyrite), but the proportions of them in each differ, and they have the same bonanzas, wall rocks, and gangue minerals (mainly quartz).

It is suggested by Spurr that the alteration of the wall rocks was caused by descending atmospheric waters, changing them to mixtures of quartz, sericite, carbonates, and kaolin, and the gangue minerals have, moreover, come from the walls; but while the source of the metals in the silver veins is in doubt, Spurr considers that the metalliferous minerals of the gold veins were contributed by magmatic waters.

Crosby has questioned whether the gold and silver veins represent distinct classes, and points out that since the former outcrop at low levels, they may simply represent the basal portions of silver veins, these being known to outcrop only at the higher points in the district.

Goldfield, Nevada (88, 89). — Goldfield lies near the eastern border of Esmeralda County (Fig. 195), on the southern rim of one of the typical desert basins of the region which connects, through a low pass on the north, with a still larger basin west of Tonopah.

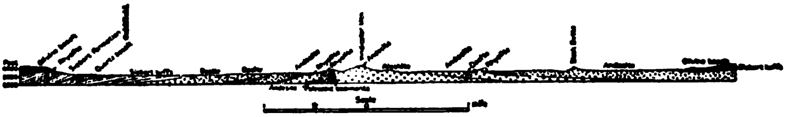

FIG. 210. — Geologic section across the Goldfield district. (*After Ransome.*)

The geologic structure (Fig. 210) of the district is quite simple, consisting essentially of a low dome-like uplift of Tertiary lavas and lake sediments, resting on a foundation of ancient granitic and metamorphic rocks.

The kind of rocks in this district, their age, and relationships are shown in the columnar section given by Ransome (Fig. 211). The oldest or Cambrian beds were intruded by alaskite at about the close of Jurassic time, and there then followed a long interval of erosion before the eruption of the Tertiary lavas. It will be seen from the

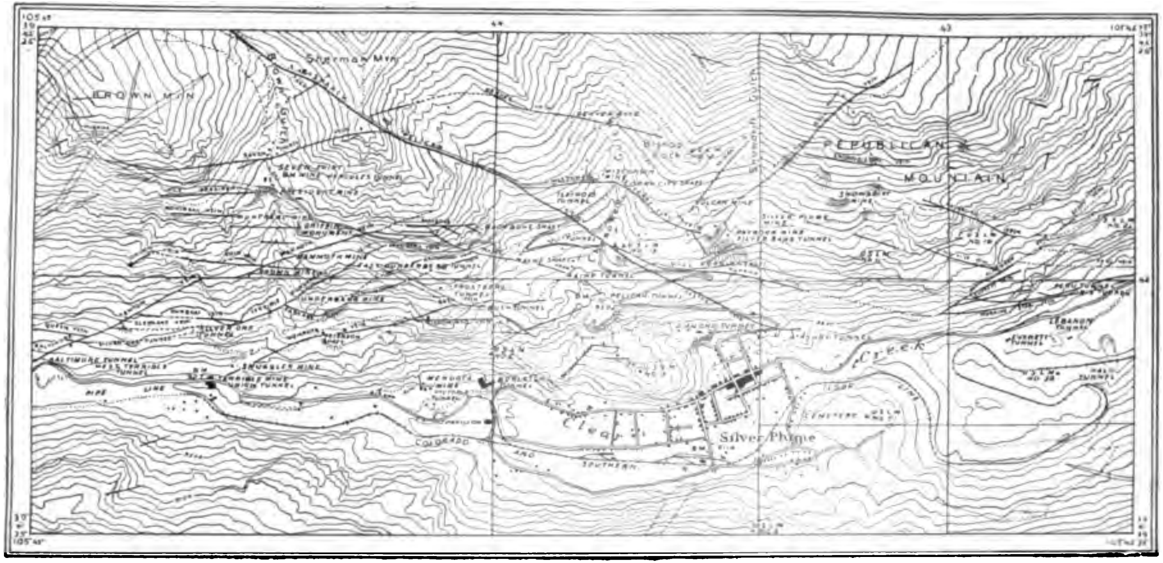

Plate LI. — Map showing veins and porphyry dikes in the Silver Plume, Col., region. (*After Spurr, U. S. Geol. Surv., Prof. Pap.* 63.)

section that the same type of rock was in some cases erupted more than once.

The ores of this district, which are of somewhat complex character, consist of native gold and pyrite, accompanied by minerals containing copper, silver, antimony, arsenic, bismuth, tellurium, and other elements.

The free gold occurs in some of the ores, in fine particles, closely crowded together and forming bands or blotches in the flinty gangue, and is not likely to be recognized as such until examined with a lens. The common associated minerals are pyrite, marcasite, bismuthinite, and famatinite (?). At times the rich ore shows a curious concentric crustification, consisting of fragments of silicified, alunitized, and pyritized rock, covered with shells of gold and sulphides.

The ore bodies, which are noted for their remarkable richness and irregularity (Pl. LII) are closely related to fissures, usually of irregular trend, but not representing fault planes.

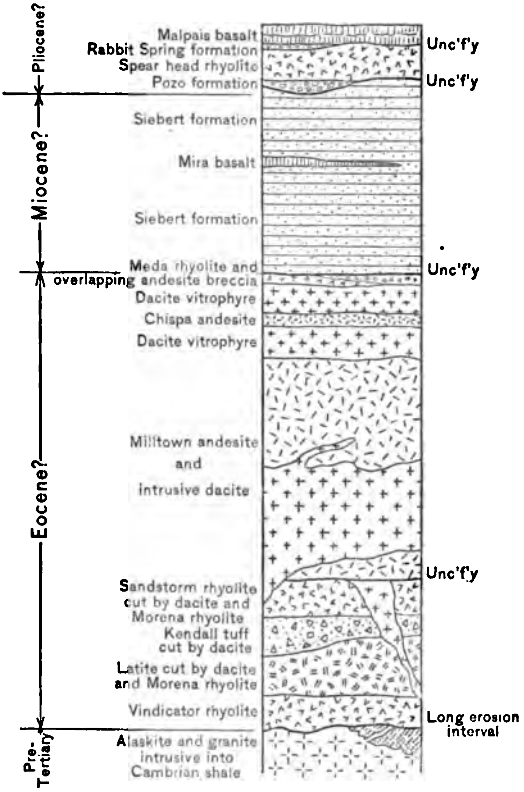

FIG. 211. — Generalized columnar section of geological formations at Goldfield, Nev. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 66.)

The deposits (Pl. L II) are defined as irregular masses of altered and mineralized rock, traversed by multitudes of small, irregular, intersecting fractures, such fracturing passing in many places into brecciation.

These irregular masses are termed ledges (Fig. 212), and within them occur the actual ore bodies or pay shoots. Capping these ledges of soft rock are craggy outcrops (Pl. LIII, Fig. 2) of silicified and alunitic material which stand out in relief on the surface because more resistant than the surrounding rocks. The ores are almost invariably associated with these, but every siliceous knob is not underlain by ore.

The most important ore bodies are found in dacite, but some small although rich ones are known in the Milltown andesite (Fig. 211).

The alteration of the rock adjoining the fissures is of three types. Where it is most intense the rock has been changed to porous, fine-grained aggregates consisting essentially of quartz. A second type is the change to a soft, light-colored mass of quartz; while a third, which is of propylitic character, consists in the development of calcite, quartz, chlorite, epidote, and gypsum.

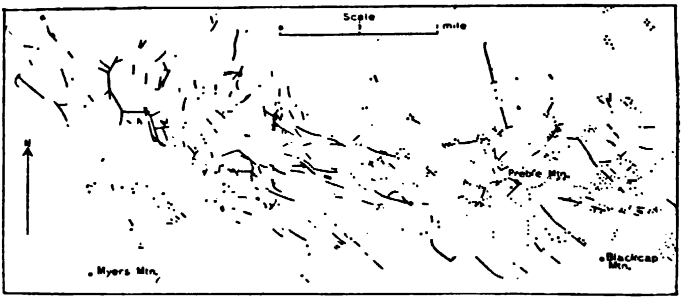

FIG. 212. — Map showing outcrops of siliceous ledges east of Goldfield, Nev. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 66.)

Most of the ore produced during the first two or three years of the camp was oxidized in character, but now some of the mines are working in sulphides.

Origin. — Ransome's theory is that after the dacite had solidified, but not perhaps entirely cooled, the subjection of the rocks to stresses of unknown origin developed a complicated system of fractures.

Hot waters carrying hydrogen sulphide with some carbon dioxide and the metallic constituents of the ores rose along these fissures; oxidation of a part of the hydrogen sulphide to sulphuric acid occurred in the upper parts of the fissure zones or at the surface.

These acid solutions then percolated downward through the shattered rocks, changing their feldspars to alunite, mingled with the rising solutions, and precipitated most of their metallic load as ore, but the original solutions were not everywhere rich in metals.

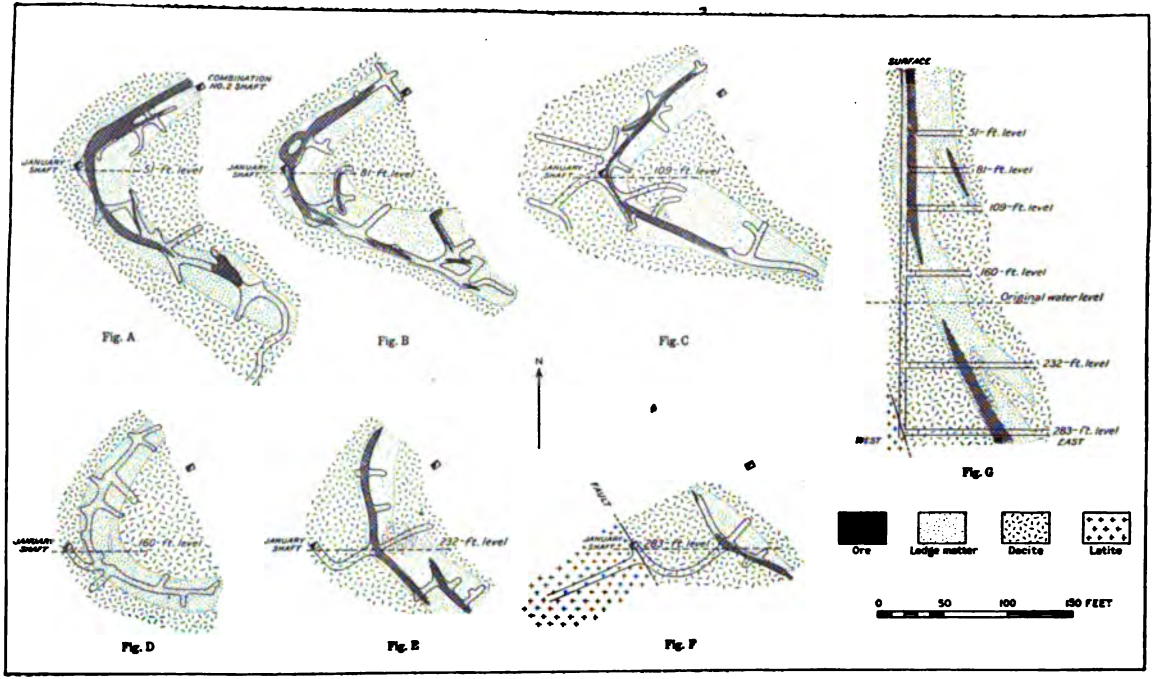

Plate LII. — Plans of the principal levels of the January mine, with a diagramatic section, showing relation of ore, ledge matter, and country rock. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 66.)

Following this the ledges were fractured, and a second stage of mineralization occurred, during which further deposition of ore and in some cases repeated precipitation followed more fracturing.

The ledges are thought to have been formed during the first stage of deposition, and the softening and alunization of the rock, as well as the propylitization, are believed to have occurred at the same time. Some good ore was also deposited then.

The Goldfield mining district may be classed as one of the newer ones of Nevada. For some years the total production of the state had been small but the discovery of Tonopah in 1900 gave a new impetus to the search for precious metals in this region, and the finding of the Goldfield deposits may be rightly reckoned as one of the results.

Comparatively young as this camp is, its production has none the less been remarkable, the shipments for the first five years being as follows:—

Year	Gold Value	Silver Value	Total Value	Average Value per Ton
1903	$70,670	$155	$70,825	$211.41
1904	2,341,979	11,374	2,353,353	316.60
1905	1,882,951	5,188	1,888,139	96.58
1906	7,026,154	10,484	7,036,638	118.00
1907	8,408,396	47,329	8,455,725	83.61
1908	19,730,150	74,530	19,804,680	105.29

Tonopah, Nevada (91). — This district, although opened up only in 1900, produced during the first three years over $3,000,000 worth of gold. Tonopah lies in the arid desert region of Nevada, and contains a series of Tertiary lavas and tuffs, the former including andesites, dacites, rhyolites, and basalt (Fig. 213). The earlier lavas and tuffs have been broken by a complex series of faults which have not, however, affected the older dacites and closely associated rhyolite necks. Four periods of vein formation have been discovered closely following periods of eruption,

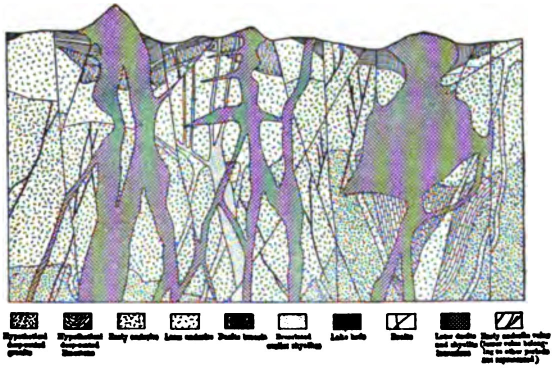

Fig. 213. — Ideal cross section of rocks at Tonopah, Nev. (*After Spurr, U. S. Geol. Surv., Bull.* 225.)

and of these only the oldest, namely, those found in the earlier andesite, are available sources of ore. The veins which have been formed by replacement in sheeted zones and show more or less development of ore shoots, contain quartz with orthoclase, and inclose as metallic minerals stephanite and probably polybasite. The values are about two sevenths gold and five sevenths silver. Subsequent to their formation they have been pierced and covered by later volcanic rocks, and these, together with the complex faulting, has produced most puzzling structural conditions. The Tonopah ore deposits are analogous genetically to the Comstock lode deposits of Nevada (83).

Comstock Lode, Nevada (83). — This lode, which is of historic interest, occurs near Virginia City, in southwestern Nevada, and is a great fissure vein (Fig. 214), about four miles long, several hundred feet broad, and branching above, following approximately the contact between eruptive rocks, and dipping at an angle of 35 to 45 degrees. There is abundant evidence of faulting, which in the middle portion of the vein has amounted to 3000 feet. The lode is of Tertiary age, and contains silver and gold minerals in a quartzose gangue.

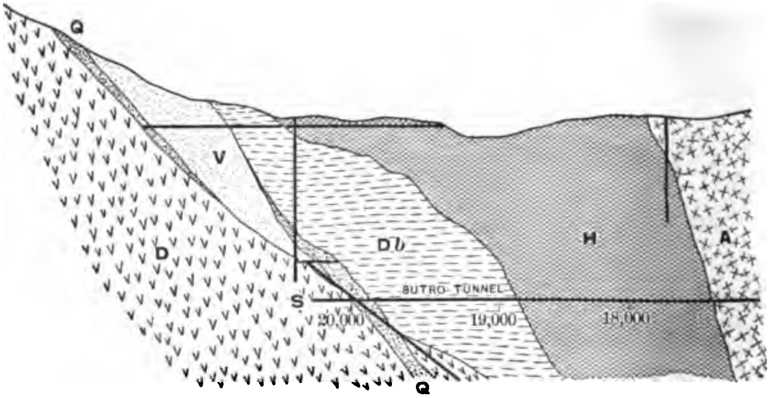

FIG. 214. — Section of Comstock lode. *D*, diorite; *V*, vein matter in earlier diabase (*Db*); *H*, earlier hornblende andesite; *A*, augite andesite. (*After Becker.*)

One of the peculiar features of the deposit is the extreme irregularity of the ore, which occurs in great "bonanzas," some of which carried several thousand dollars to the ton. The faulting is considered to have been quite recent, and the high temperatures encountered in the lower levels of the mine indicate that there is probably a partially cooled mass of igneous rock at no great depth.

PLATE LIII

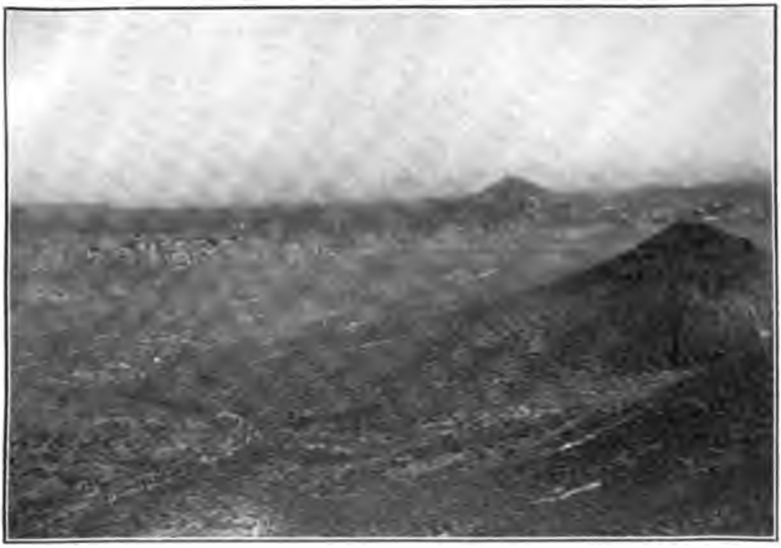

FIG. 1. — General view of Goldfield, Nev., and surrounding country. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 66.)

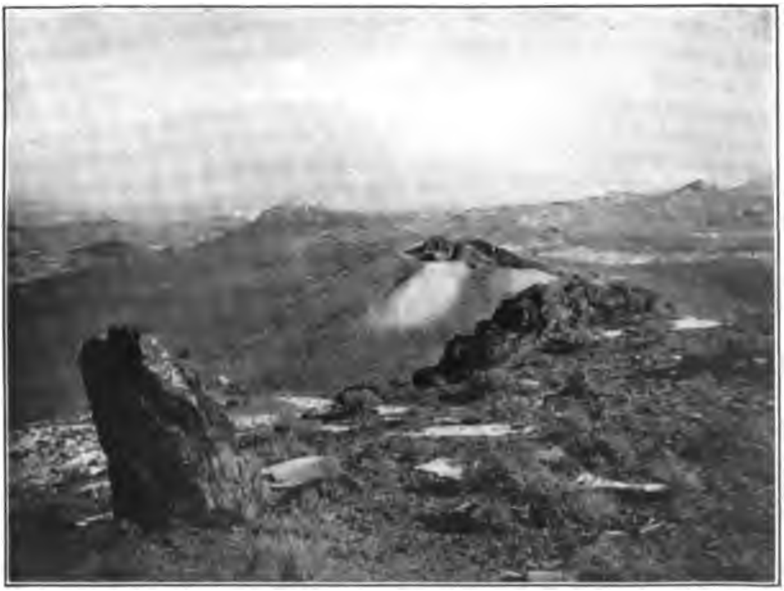

FIG. 2. — Ledge outcrop in dacite between the Blue Bell and Commonwealth mines, Goldfield, Nev. The conspicuous white dump is alunitic material. The rough knob on sky line near right side of view is Barner Mountain. (*After Ransome, U. S. Geol. Surv., Prof. Pap.* 66.)

In former years the enormous output of this mine caused Nevada to be one of the foremost silver producers. It was discovered as early as 1858, and increased until 1877, after which it declined. Many serious obstacles were met with in the development of the mine, such that it has never become a source of much profit in spite of its enormous output. In 1863, at a depth of 3000 feet, the mine was flooded by water of a temperature of 170 F., due to a break in the clay wall; and to drain it $2,900,000 were spent in the construction of the Sutro tunnel, which was nearly four miles long, but by the time it was finished the workings were below its depth. A second difficulty was the encountering of high temperatures in lower workings, those in the drainage tunnel mentioned being 110° to 114° F. The mine is credited with a total production of $368,000,000. In recent years its output has been slowly increasing again.

Other occurrences of the propylitic type are found in Gilpin and Boulder counties, Colorado.

In Arizona the Commonwealth mine of Cochise County (36) is probably referable to this group, as is also the Congress Mine (34).

Fissure veins associated with Tertiary eruptives are found in Owyhee County, Idaho, in the Monte Cristo district of Washington (122), and the Bohemia district of Oregon (102). The auriferous copper veins of Butte, Montana, also belong in this group, but since they are more important as producers of copper, they are described under that head.

Auriferous Gravels (42, 50, 53). — These form an important source of supply of gold, together with a little silver, and, although widely distributed, become prominent chiefly in those areas in which auriferous quartz veins are abundant. So, while they are found in many parts of the Cordilleran region, in the Black Hills, and in the Atlantic states, their greatest development is in the Pacific coast belt from California up to Alaska.

These auriferous gravels represent the more resistant products of weathering, such as quartz and native gold, which have been washed down from the hills on whose slopes the gold-bearing quartz veins outcrop, and were too coarse or heavy to be carried any distance, unless the grade was steep. They have consequently settled down in the stream channels, the gold, on account of its higher gravity, collecting usually in the lower part of the gravel deposit.

Although the gold-bearing gravels have been derived from veins of varying age, the deposition of the gravel has rarely occurred in pre-Tertiary times, and some, indeed, are of very recent origin.

The gold occurs in the gravels in the form of nuggets, flakes, or dustlike grains, the last being usually hard to catch. The nuggets represent the largest pieces, and the finding of some very large ones has been recorded from time to time in different parts of the world. Two large nuggets are recorded from Victoria: one, the "Welcome Stranger," weighing 2280 ounces; and the other, the "Welcome Nugget," weighing 2166 ounces. Since the auriferous gravels of the Pacific coast belt are the most important, they will be specially referred to.

These have been derived from the wearing down of the Sierras, and are found in those valleys leading off the drainage from the mountains. Many were formed during the Tertiary period, when the Sierras were subjected to a long-continued denudation, while violent volcanic outbursts at the close of the Tertiary have often covered the gravels and protected them from subsequent erosion. These lava cappings are at times 150 to 200 feet thick, as in Table Mountain, Tuolumne County.

Many of the gravel deposits are on lines of former drainage, while others lie in channels still occupied by streams. Some show but one streak of gold, while in others there may be several, some of which are on rock benches of the valley bottom (Fig. 215).

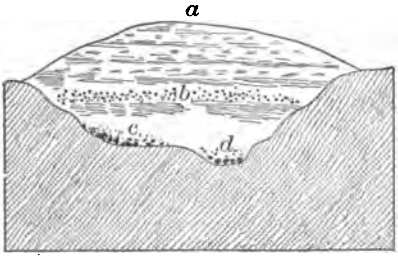

FIG. 215. — Generalized section of old placer, with technical terms. *a*, volcanic cap; *b*, upper lead; *c*, bench gravel; *d*, channel gravel. (*After R. E. Browne.*)

During the early days of gold mining in California the gravels at lower levels and in the valley bottoms were worked, but as these became exhausted, those farther up the slopes or hills were sought.

In the earlier operations the gravels were washed entirely by hand, either with a pan or rocker, and this plan is even now followed by small miners and prospectors; but mining on a larger scale is carried on by one of three methods, viz. drift mining, hydraulic mining, and dredging.

Drift mining is employed in the case of gravel deposits covered by a lava cap, a tunnel being run in to the paying portion of the bed and the auriferous gravel carried out and washed.

In hydraulic mining (Pl. LIV, Fig. 1), a stream is directed against the bank of gravel and the whole washed down into a rock ditch lined with tree sections, or into a wooden trough with crosspieces or riffles on the bottom. The gold, being heavy, settles quickly

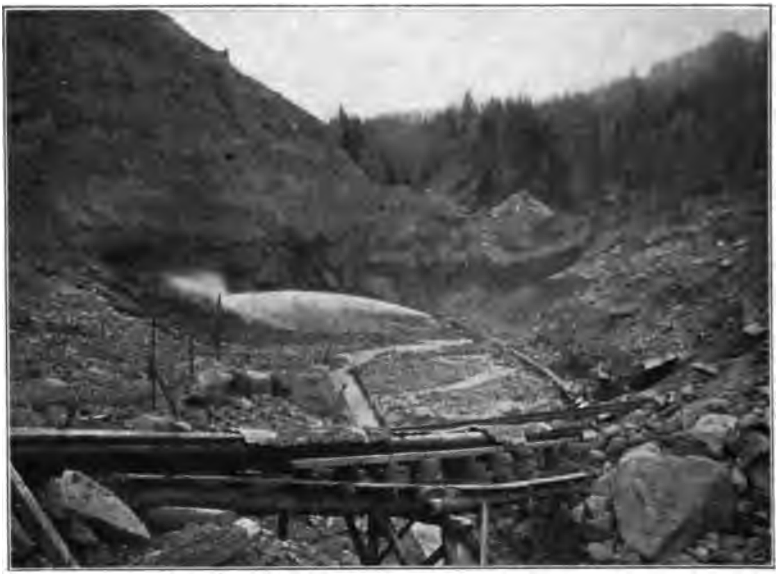

FIG. 1. — Hydraulic mining of auriferous gravel. The sluice box in foreground is for catching the gold.

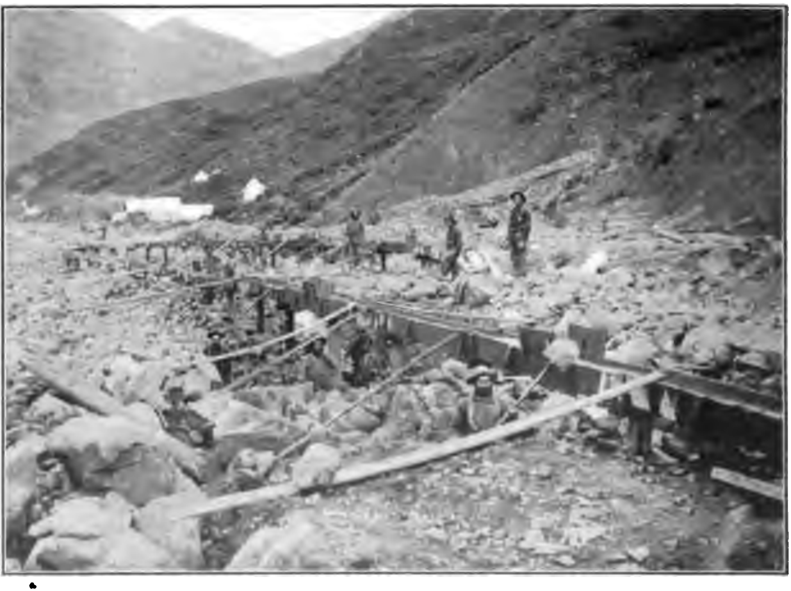

FIG. 2. — An Alaskan placer deposit.

and is caught in the troughs or ditches, while the other materials are carried off and discharged into some neighboring stream. Mercury is sometimes put behind the riffles to aid in catching the gold.

The water which is used to wash down the gravel deposits is often brought a long distance, sometimes many miles, and at great expense, bridging valleys, passing through tunnels, and even crossing divides, this being done to obtain a large enough supply as well as a sufficient head of water.

Owing to the great amount of débris which was swept down into the lowlands, a protest was raised by the farmers dwelling there, who claimed that their farms were being ruined; and it soon became a question which should survive, the farmer or the miner, for in places the gravels and sand from the washings choked up streams and accumulated to a depth of 70 or 80 feet. The question was settled in 1884 in favor of the farmer by an injunction, issued by the United States Circuit Court, which caused many of the hydraulic mines to suspend operations; and at a later date this was extended by state legislation, adverse to the hydraulic mining industry. Owing to this setback, hydraulic mining fell to a comparatively unimportant place in the gold-producing industry of California, while at the same time quartz mining increased.

The passage of the Caminetti law now permits hydraulic mining, but requires that a dam shall be constructed across the stream to catch the tailings. This resulted in a revival of the industry, but even so, the placer mining industry is seriously hindered by the present laws governing it.

Dredging consists in taking the gravel from the river with some form of dredge. The method, which was first practiced in New Zealand, has been introduced with great success into California, especially on the Feather River, near Oroville, and its use has spread to other parts of the Cordilleran region. The gravel when taken from the river is discharged on to a screen, which separates the coarse stones, and the finer particles pass over amalgamated plates, tables with riffles, and then over felt.

Formerly much placer gold was obtained by hydraulic mining, but the annual supply from this source is slowly decreasing, as is that from drift mining, while the returns of dredger gold have been continually increasing since 1900, being $200,000 in that year and $1,500,000 in 1903. This is due to the fact that large areas in Yuba, Sutler, Nevada, Butte, and Sacramento counties have been found adapted to dredging processes, while the improvement and enlargement of the dredging machines has greatly decreased the cost of mining.

Placer gold is also worked in Idaho, Montana, Oregon, New Mexico, and Colorado, all of the deposits except those of the last two states having been derived mostly from Mesozoic veins.

Gold also occurs in beach sand of certain portions of the Pacific coast of Washington (119), and placer mining has been carried on since 1894; but the supply of gold, which is obtained from Pleistocene sands and gravels, is small.

In arid regions, where the gold-bearing sands are largely the product of disintegration, and water for washing out the metal is wanting, a system known as dry blowing is sometimes resorted to.

Black Hills Region. — The gold-bearing ores are found chiefly in the northern Black Hills and include (1) auriferous schists in pre-Cambrian rocks; (2) Cambrian conglomerates; (3) refractory siliceous ores; (4) high-grade siliceous ores; and (5) placers. Of these the first and third are the most important.

The surface placers, being the most easily discovered, were developed first, followed by the conglomerates at the base of the Cambrian.[1] These are found near Lead, occupying depressions in the old schist surface, and the material is thought to have been derived from the reef formed by the Homestake ledge in the Cambrian sea. These deposits are of interest as being probably the oldest gold placers known in the United States. The fact, however, that the matrix of the gold-bearing portion of the conglomerate is pyrite rather than quartz, and the occurrence of the gold along fractures stained by iron, has led some to believe that the gold has been precipitated chemically by the action of iron sulphide and is not a detrital product.

Homestake Belt. — The gold ores of the Homestake belt (109, 110), which belong to the first type mentioned above, and are the most important in the Black Hills, occur in a broad zone of impregnated schists, containing many quartz lenses, alternating with dikes of fine-grained rhyolite, which also formed sheets in the Cambrian sediments overlying the schists, and now remain as a resistant cap on many of the surrounding ridges (Fig. 216). The ore, which is all low grade, averaging $5 to $6 per ton, is usually a mixture of quartz, pyrite, and occasionally other minerals having no definite connection with it, occupying a zone in the Algonkian rocks which shows greater hardness, irregularity of structure, and mineralization

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[1] These are referred to as cement mines, owing to their partly cemented character.

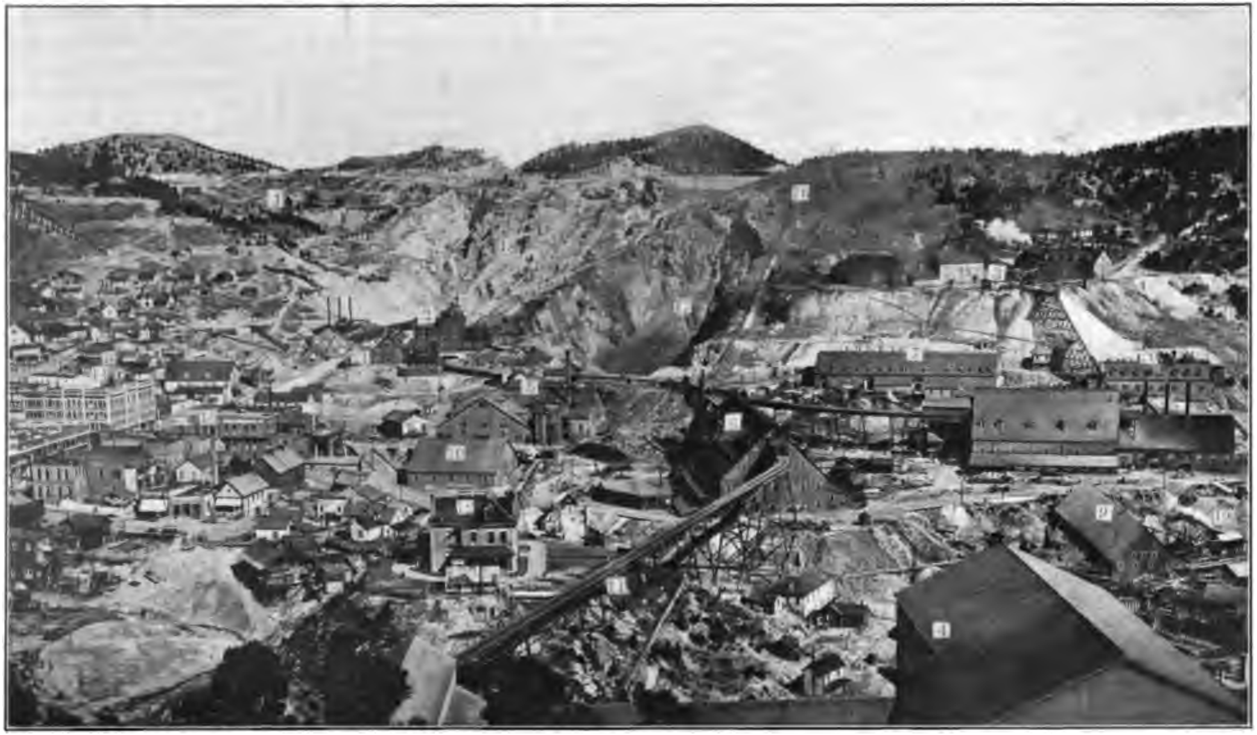

Plate LV. — Homestake mills, hoists, and open cuts at Lead, S. Dak. (*After O'Harra, S. Dak. Sch. of Mines, Bull.* 6.)

1. Highland hoist and sawmill.
2. Golden Star hoist.
3. Old Abe hoist.
4. Ellison hoist.
5. Homestake mill.
6. Golden Star mill.
7. Amicus mill.
8, 9, 10. Plate houses.
11. Steel bridge.
12. Superintendent's residence.
13. Coal chute.
14. Hotel Smead.
15. Office, Hearst free library, and company store.
16. Old experimental cyanide plant.
17, 18. Open cuts.
19. Wood chute.
20. Shop.
21. Miners' bath and dressing rooms.

than the surrounding schists. The boundaries are poorly defined, and superficial examination may fail to distinguish between ore and barren rock. In the upper levels the ore seems to be with the dikes, but diverges from them in depth, and there is apparently no genetic relation between the two. In the earlier days the ore encountered was oxidized and free-milling, but the appearance of sulphides with depth has necessitated the introduction of the cyanide method of extraction. In spite of the low grade of its ores the Homestake mine, due to proper management, stands out as one of the richest mines of the world, its monthly production amounting to about $300,000 (Curle). The ore was originally worked as an open cut (Pl. LV), but later by underground methods.

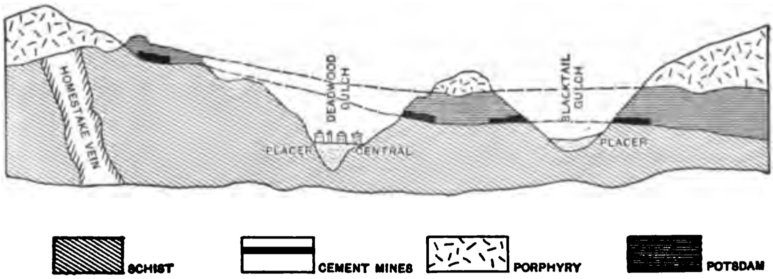

FIG. 216. — Section of Homestake belt at Lead, S. Dak., showing relation of ancient and modern placers to Homestake lode. (*From Min. Mag.*, XI.)

Siliceous Cambrian Ores (109, 111). — Another important type is the refractory siliceous Cambrian ore found in the region between Yellow Creek and Squaw Creek, and yielding about two thirds as much gold as the Homestake. The deposits, which occur as replacements in a siliceous dolomite (Fig. 217), are found at two horizons, one immediately overlying the basal Cambrian quartzite, and the other near the top of the Cambrian series. The ore forms flat banded masses known as shoots, and varying in width from a few inches to 300 feet. It is overlain by shale or eruptive rock, and associated with a series of vertical fractures, made prominent by a slight silicification of the wall rock. These fractures, which are termed *verticals*, are supposed to have conducted the ore-bearing solutions.

The ore is a hard, brittle rock, composed of secondary silica, with pyrite and fluorite, and at times barite, wolframite, stibnite, and jarosite. Its contents range from $3 or $4 per ton to in rare cases $100 per ton, with an average of $17. Other, but less important, siliceous ores occur in the Carboniferous rocks.

Michigan Region (76). — A small amount of gold has been found in a quartzose zone in schists, near Marquette, Michigan, but the area is of little importance.

Eastern Crystalline Belt (113). — Gold, with some silver, has been found in the rocks of this belt from Vermont to Alabama, but the deposits are of little importance except in North Carolina (95–97), South Carolina (106, 107), Georgia (69–71), and Alabama (22, 23), in other words, in the southern Appalachian and Piedmont region; but even in this part of the area the deposits are not found everywhere, but are restricted to three belts (Becker), viz.: (1) the Georgia belt, extending from Montgomery, Alabama, across northern Georgia to North Carolina; (2) the South Mountains region of North Carolina; (3) the Carolina belt, lying to the eastward of the others, and extending from South Carolina northeastward through Charlotte, North Carolina, and continued in Virginia; at least the Virginia deposits lie in part in the line of strike of this zone.

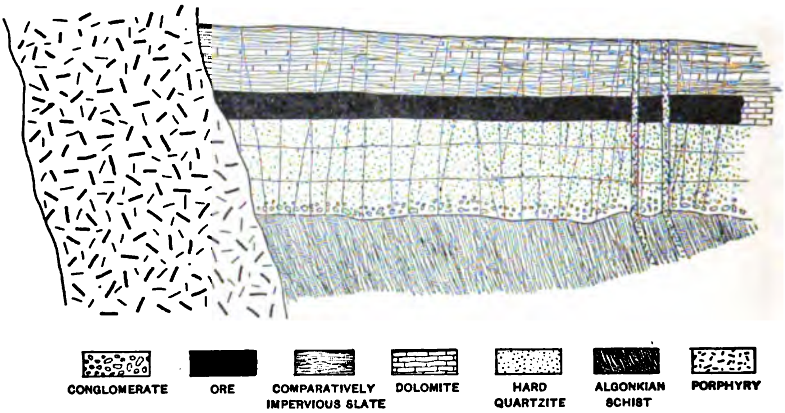

FIG. 217. — Typical section of siliceous gold ores, Black Hills, S. Dak. (*After Irving, U. S. Geol. Surv., Prof. Pap.* 26.)

The ores of the southern Appalachian region occur as auriferous pyrite in quartz veins, as replacements in metamorphic rocks, or in placers derived from either of the foregoing groups. The last-named type is practically exhausted.

In the Carolina belt Graton (106) states that the quartz veins with more or less pyrite occur in dense metamorphic rocks, and most commonly in amphibole or gabbro closely related to it, and formed by the filling of fracture spaces. The veins, which are irregular and have a steep dip, conform usually somewhat closely to the strike and dip of the inclosing rocks.

Similar occurrences are found in the other belts of the southern Appalachians, and some, as those at Gold Hill, North Carolina, have shown copper with depth, so that they are now worked for both metals.

The replacement type, which is important in the Carolina belt, is less common but more productive than the preceding, and with one or two exceptions is found in volcanic rocks, mostly tuffs. The porous nature and easily alterable character of these, especially the tuffs, has allowed widespread penetration and replacement by the ore solutions, which deposited chiefly silica and pyrite.

The ore bodies are usually large, and range from 40 or 50 to hundreds of feet in length, and 20 to several hundred feet in width; but their outline is rudely lenticular.

At the Haile Mine in South Carolina, which belongs to this type, the country rock is a quartz-sericite schist, which has been derived by foliation from a porphyry tuff which had an original well-bedded structure that is still preserved in some cases. The silicification appears to correspond in intensity with the amount of foliation, although in cases of extreme silicification all traces of former structure have been quite destroyed, and the rock is simply a massive siliceous hornstone. Several dikes of diabase cut the schist.

The ore consists of large lenses of altered tuff, which have been silicified and pyritized, the two processes having gone on at the same time, so that the rock now consists of a fine-grained aggregate of quartz and pyrite with scattered fibers of sericite. The replacement is not uniform. The gold occurs (1) mainly as native gold originally deposited, (2) free gold derived from oxidation of the inclosing pyrite, and (3) gold in pyrite.

This mine, which has been worked more or less continuously since about 1830, has been one of the most important producers in the southern Appalachian region.

Alaska (24). — Although gold has been known to occur in Alaska since the early part of the century, and was even worked in 1860, its production is not definitely stated until 1880, when it was added to the list of gold-producing regions, with an output of $6000, which since that time has increased many times over, but not steadily, until in 1903 it amounted to $8,283,400, reached a maximum of $22,036,794 in 1906, and had dropped to $19,292,818 in 1908.

The first gold was discovered on the islands of the Alexander

Archipelago and along the adjoining coast, but subsequently prospectors found their way into the interior, the first strikes there being made in British Columbia near the head of the Stikine River. These were followed by discoveries in the Yukon Valley, especially along some of the tributaries known as Birch Creek, Mission Creek, and Forty Mile Creek. In 1896 still richer discoveries were made along the Klondike River, and within one year the yield of this region had exceeded the purchase price of Alaska. Other discoveries have since followed rapidly.

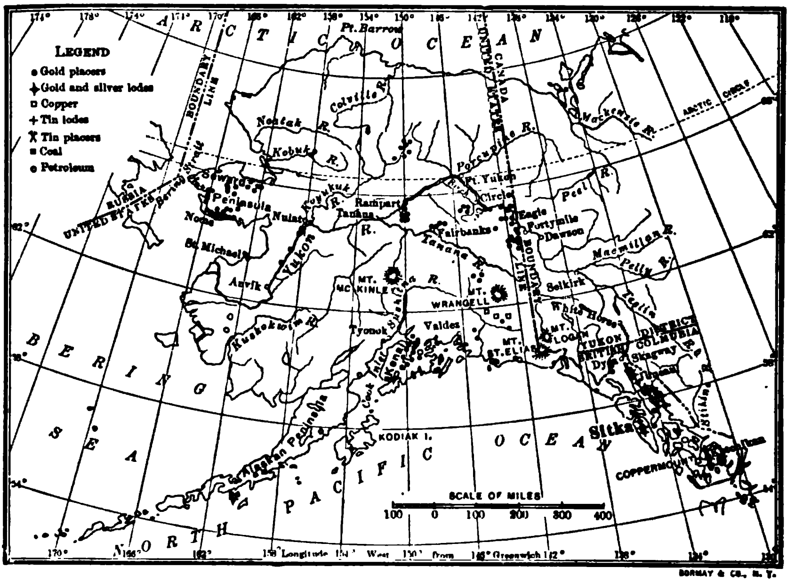

FIG. 218. — Map showing mineral deposits of Alaska. (*After Brooks, U. S. Geol. Surv., Bull.* 250.)

At the present time approximately 80 per cent of the value of the gold produced in Alaska is obtained from placers, 16 per cent from quartz ores, and 2 per cent from copper ores.

Auriferous Lodes (32).—The gold quartz lodes, which are most prominent along the coast (Fig. 218), were first discovered near Sitka in 1897, but the first important production came from the Treadwell mine on Douglas Island southeast of Juneau (32) in 1882.

The geology of this region bears in many ways a strong resemblance to the California gold belt, and is probably of similar age. The section involves a series of steeply dipping slates and greenstone and diorite dikes. The ore bodies (Figs. 219, 220) are dikes of albite-diorite, permeated with metallic sulphides and carrying small amounts of gold, with a hanging wall of greenstone and a foot wall of black slate. The veinlets, which are thought to have been formed by shearing stresses incident to epeirogenic movements, occur in two sets of fractures at right angles to each other. Spencer believes that the mineralization has been caused by hot ascending solutions of magmatic origin. Secondary concentration is not in evidence, and it is thought that the depth to which the ores can be worked will depend more on the increased cost of mining at great depths than on exhaustion of the ore. At present an almost continuous ore body has been developed for 3500 feet.

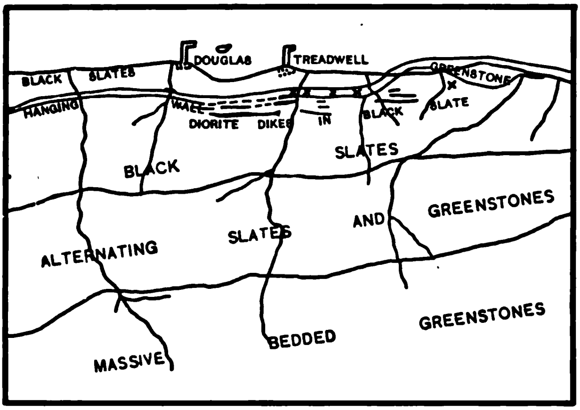

Fig. 219. — Sketch map of Douglas Island, Alaska. (*After Spencer, U. S. Geol. Surv., Bull.* 259.)

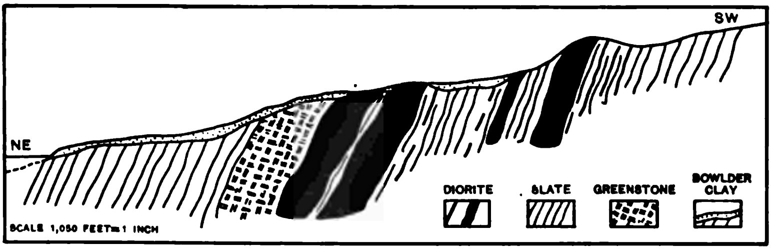

Fig. 220. — Cross section through Alaska Treadwell mine on northern side of Douglas Island. (*After Spencer, U. S. Geol. Surv., Bull.* 259.)

Placer Deposits. — The placer deposits have been found in many parts of Alaska, but the two regions which have yielded the largest amount are the Yukon region (33) and the Seward Peninsula (24, 30), the latter being now the first.

Gold was discovered in the Forty Mile district of the Yukon in 1886, and caused a stampede for this region; but the deposits of the Klondike did not become known until 1896, and their discovery was followed by a rush of gold seekers that eclipsed all previous ones. Indeed, it is said that by 1898 over 40,000 people were camped out in the vicinity of the present site of Dawson.

The Klondike region proper is situated on the eastern side of the Yukon River, and the richer deposits found have been on the Canadian side of the boundary. The gold has collected either at the bottom of the gravel in the smaller streams tributary to the Yukon, or else in gravels on the valley sides, this latter occurrence being known as bench gravel. The metal is supposed to have been derived from the quartz veins found in the Birch Creek, Forty Mile, and Rampart series of metamorphic rocks lying to the east. Up to the end of 1902 the total production of the Klondike is stated to have been $80,000,000. The annual output has, however, decreased, and mining in that region has settled down to a more permanent basis. Gravels running under 50 cents per cubic yard cannot be worked at a profit, even by dredging, because the difficulties and expenses of mining in such a region are great, and form an interesting comparison with conditions in California, where gravel carrying 25 cents per yard is considered good, while that running as low as 5 cents per yard can be worked as a dredge proposition (26).[1]

Since the discovery of the rich gold gravels on the Yukon, auriferous gravels have been developed in many other parts of Alaska, where they are being more or less actively worked (Fig. 218), but of these various finds those in the Seward Peninsula, which is now the largest producer, have been the most important.

The first of the localities discovered in the last-mentioned region was Cape Nome (30, 31), which for a time proved to be a second Klondike. The gold was discovered here on Anvil Creek, and the following year in the beach sands where Nome now stands. These discoveries caused another northward stampede, which resulted in the rapid exhaustion of the beach sands; but other deposits were found farther inland near Nome, as well as the other localities on the Seward Peninsula. Some quartz veins are also worked. Ophir Creek is now the largest producer on the Seward Peninsula. Up to the end of 1908 the Seward Peninsula had produced $49,362,700 in gold, and

[1] See also U. S. Geol. Surv., Bull. 263.

in 1908 its production is given as $5,100,000, which is a slight falling off from 1907. In the Fairbanks district (29), which is the other important placer area, and lies in central Alaska (Fig. 218), there is a remarkable accumulation of unconsolidated material overlying the bed rock, which seems to have been deposited in an area where glaciation was absent, but fluviatile conditions predominated.

An interesting feature of these deposits is their remarkable thickness, and their depth of consolidation by ice, over 300 feet, as revealed by mining operations. The unconsolidated material includes slide rock, muck, sand, silt, clay, barren gravels, and the gravels in which the gold is found. These productive gravels, so far as discovered, are a thin layer next to bed rock, and the value of the gold recovered ranges from less than $1 to $8 or more per square foot of bed rock surface.

The total length of ground over which productive areas are scattered is about 75 miles.

Uses of Gold. — Gold is chiefly used for coinage, ornaments, and ornamental utensils. It is also employed to a considerable extent in dentistry and in an alloy for the better class of gilding.

Its value for use in the arts depends on its brightness, freedom, from tarnish, and its ductility and malleability, which permit it to be easily worked. As pure 24-carat gold is too soft for use, it is alloyed with a small amount of some other metal, such as copper, to gain hardness.

Uses of Silver. — This metal was formerly of much importance for coinage, but is much less so now. It is, however, widely employed in the arts for making jewelry and utensils such as tableware. Its salts are of more or less value in medicine and in photography. Its brightness and white color are valuable properties when the metal is used, but, unlike gold, it tarnishes somewhat readily when exposed to sulphurous gases. There are a number of alloys of silver, those with gold and copper, respectively, being of importance.

Production of Gold and Silver. — The total production of gold and silver for the United States is given in the chart, Fig. 221, while the production of gold in the more important states is shown in Fig. 222, in which the overwhelming importance of Alaska, California, Colorado, and Nevada is well brought out.

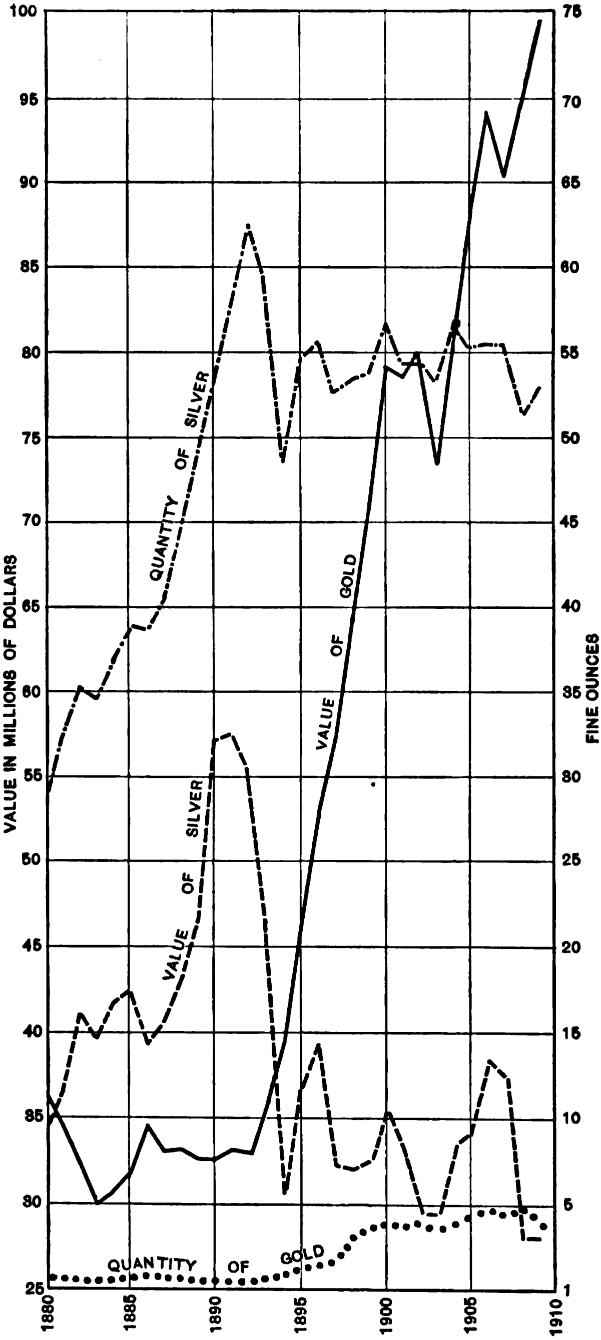

FIG. 221. — Chart showing quantity and value of gold and silver produced in the United States from 1880 to 1909. (*U. S. Geol. Surv., and Eng. and Min. Jour.*)

The production for 1908 is given below:—

APPROXIMATE DISTRIBUTION BY PRODUCING STATES AND TERRITORIES OF THE PRODUCT OF GOLD AND SILVER IN THE UNITED STATES FOR 1908 IN FINE OUNCES

STATE OR TERRITORY	GOLD		SILVER	
	Quantity	Value	Quantity	Commercial Value
Alabama . . .	1,993	$41,200[1]	400	$200
Alaska . . .	960,669	19,858,800	204,600	109,400
Arizona . . .	120,937	2,500,000	2,900,000	1,551,200
California . .	935,074	19,329,700	1,703,700	911,300
Colorado . . .	1,106,385	22,871,000	10,150,200	5,429,400
Georgia . . .	2,719	56,200	200	100
Idaho	69,829	1,443,500	7,558,300	4,042,900
Illinois . . .	——	——	2,000	1,100
Michigan. . .	——	——	294,100	157,300
Missouri . . .	——	——	49,400	26,400
Montana . . .	152,865	3,160,000	10,356,200	5.539,500
Nevada . . .	565,475	11,689,400	9,508,500	5,086,100
New Hampshire	179	3,700	6,300	3,400
New Mexico .	14,817	306,300	400,900	214,500
North Carolina	4,716	97,500	1,300	700
Oregon . . .	43,823	905,900	56,100	30,000
Philippine Islands . . .	13,763	284,500	1,300	700
Porto Rico . .	29	600	——	——
South Carolina	2,598	53,700	200	100
South Dakota .	374,529	7,742,200	197,300	105,500
Tennessee . .	179	3,700	60,900	32,600
Texas	24	500	447,000	239,100
Utah	190,922	3,946,700	8,451,300	4,520,600
Virginia . . .	174	3,600	300	200
Washington . .	12,273	253,700	86,800	46,400
Wyoming . .	368	7,600	3,500	1,900
	4,574,340	$94,560,000	52,440,800	$28,050,600

The basis for this table is data collected by the Bureau of the Mint of bullion deposits in the United States mints and assay offices and statements from the smelting and refining establishments. The table is derived from three items: (1) the unrefined domestic gold and silver deposited in the United States mints and assay offices; (2) the domestic gold and silver in fine bars reported by the private refineries; (3) the unrefined

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[1] Gold value, $20.671834625323 per fine ounce. Average commercial silver value, 53 cents per fine ounce.

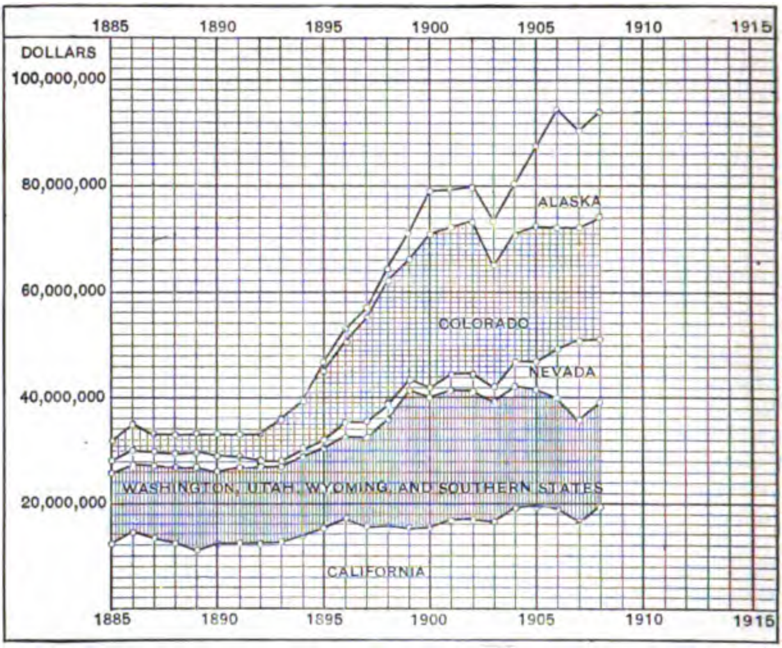

Fig. 222. — Chart showing production of gold of the United States, and of the principal states and territories, from 1885 to 1908. (*U. S. Geol. Surv.*)

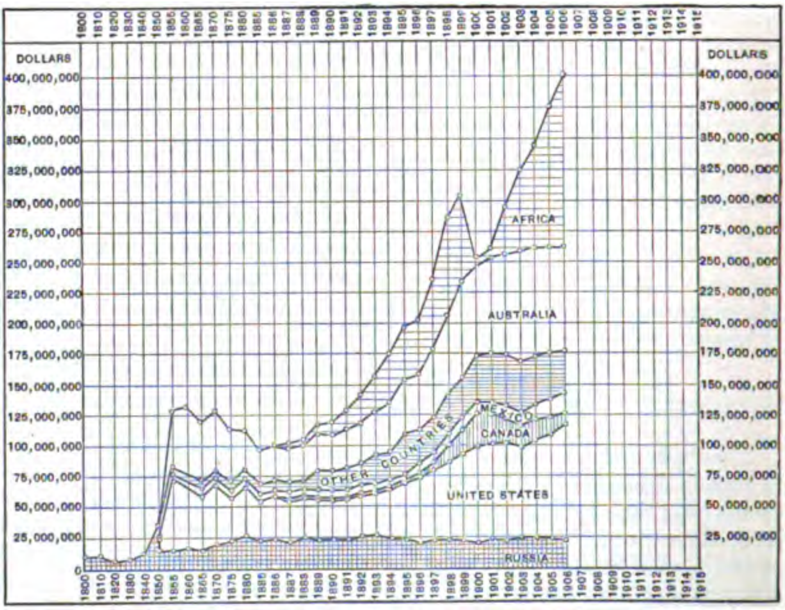

Fig. 223. — Chart showing production of gold in the principal countries of the world from 1800 to 1906.

domestic gold and silver contained in ores, copper matte, etc., exported for reduction. The last is an item of small relative importance.

In addition, gold and silver were produced in the smelters and refineries of the United States from foreign ore, matte, and unrefined bullion as follows: gold, 892,138 fine ounces, or $18,442,100; silver, 65,107,220 fine ounces, or $34,506,800.

The Mint Bureau does not further subdivide these figures. The foreign gold and silver were derived from Mexico, Canada, nearly all South American and Central American countries, Korea, and Japan; minor amounts were received from other sources. Of the gold, probably about $9,000,000 was derived from Mexico, and about $8,000,000 from Canada. Of the silver, about 45,000,000 fine ounces came from Mexico, and about 16,000,000 ounces were derived from Canada.

Several years ago Mr. Lindgren began the classification of the figures of gold and silver production according to the kind of ores from which they are derived. The figures for 1908 are given on the following pages and indicate that the Tertiary quartz veins yield the largest amount of gold, and also now the greatest amount of silver.

World's Production. — The chart, Fig. 223, shows graphically the output of the principal countries, but it may be of interest to give additional details in the following tables: —

Gold Production of the World, from 1890 to 1909[1]

1890	$118,848,700	1900	$258,829,703
1891	130,650,000	1901	260,877,429
1892	146,292,600	1902	298,812,493
1893	158,437,551	1903	329,475,401
1894	182,509,283	1904	349,088,293
1895	198,995,741	1905	378,411,054
1896	211,242,081	1906	405,551,022
1897	237,833,984	1907	411,294,458
1898	287,327,833	1908	443,434,527
1899	311,505,947	1909	457,567,280

Gold Production of the World in 1908 and 1909 by Countries[1]

	1908	1909
Transvaal	$145,819,016	$151,900,000
United States	94,560,000	96,500,000
Australia	73,314,671	71,980,780
Russia	30,944,561	34,160,000
Mexico	24,518,548	26,000,000
Rhodesia	12,276,394	12,605,000
British India	10,424,067	10,566,500
Canada	9,559,274	10,750,000
China, Japan, Korea	10,618,850	11,000,000
West Africa	5,773,544	4,625,000
Madagascar	1,136,850	2,480,000
Other countries	24,488,752	25,000,000
Total	$443,434,527	$457,567,280

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[1] Figures from Eng. and Min. Jour.

SOURCE OF GOLD IN 1908 IN STATES AND TERRITORIES, AS REPORTED FROM THE MINES TO THE UNITED STATES GEOLOGICAL SURVEY, BY KINDS OF ORE AND BY STATES, IN FINE OUNCES[1]

STATE OR TERRITORY	PLACERS	DRY OR SILICEOUS ORES	COPPER ORES	LEAD ORES	ZINC ORES	COPPER-LEAD AND COPPER-LEAD-ZINC ORES	LEAD-ZINC ORES	TOTAL
Alabama	45.72	1,947.72	—	—	—	—	—	1,993.44
Alaska	768,582.00	162,411.08	2,296.99	—	—	—	—	933,290.07
Arizona	1,496.58	73,523.55	41,640.36	864.84	80.00	41.56	—	117,646.89
California	398,183.66	486,210.01	22,885.83	310.91	—	—	—	907,590.42
Colorado	8,946.23	1,018,355.67	5,006.03	17,973.93	—	23,597.39	4,913.59	1,078,792.83
Georgia	541.85	2,177.16	—	—	—	—	—	2,719.01
Idaho	13,817.97	45,417.29	8,152.32	2,439.24	—	.51	—	69,827.33
Massachusetts, New Hampshire, and Pennsylvania	—	—	211.30	—	—	—	—	211.30
Montana	26,606.01	85,473.31	32,365.34	2,303.44	1,112.23	53.01	—	147,913.34
Nevada	3,857.96	534,050.81	4,629.58	7,129.35	—	14.57	—	549,682.27
New Mexico	1,122.20	9,544.82	3,757.09	26.27	—	1.99	—	14,452.37
North Carolina	849.23	3,867.09	—	—	—	—	—	4,716.32
Oregon	13,186.68	28,377.64	283.73	—	—	—	—	41,848.05
South Carolina	39.18	2,556.28	3.00	—	—	—	—	2,598.46
South Dakota	480.95	369,932.10	—	12.53	—	—	—	370,425.58
Tennessee	29.61	—	149.33	—	—	—	—	178.94
Utah	440.69	47,439.15	111,086.12	19,986.36	1.35	90.17	10.76	179,054.60
Virginia	31.98	78.85	—	7.74	—	—	—	118.57
Washington	942.24	10,737.33	36.13	2.37	—	—	—	11,718.07
Wyoming	39.67	19.98	325.37	—	—	—	—	385.02
Total	1,239,240.41	2,882,119.84	232,828.52	51,056.98	1,193.58	23,799.20	4,924.35	4,435,162.88
Value	$25,617,373	$59,578,704	$4,812,993	$1,055,441	$24,674	$491,973	$101,795	—
Per cent of total . . .	28	65	5	1	1			—

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[1] Illinois, Philippines, and Porto Rico not included.

SOURCE OF SILVER IN 1908 IN STATES AND TERRITORIES, AS REPORTED FROM THE MINES TO THE UNITED STATES GEOLOGICAL SURVEY, BY KINDS OF ORE AND BY STATES, IN FINE OUNCES [1]

STATE OR TERRITORY	PLACERS	DRY OR SILICEOUS ORES	COPPER ORES	LEAD ORES	COPPER-LEAD AND COPPER-LEAD-ZINC ORES	ZINC ORES	LEAD-ZINC ORES	TOTAL
Alabama	4	278	—	—	—	—	—	282
Alaska	70,104	31,966	33,602	—	—	—	—	135,672
Arizona	258	899,072	1,777,266	129,050	2,104	700	—	2,808,450
California	71,185	483,483	1,031,381	59,600	1,629	—	—	1,647,278
Colorado	2,119	5,553,591	193,206	1,501,803	941,394	—	713,320	8,905,433
Georgia	42	158	—	—	—	—	—	200
Idaho	2,687	918,094	631,261	5,917,034	905	—	—	7,469,981
Illinois	—	—	—	2,051	—	—	—	2,051
Massachusetts, New Hampshire, and Pennsylvania	—	—	6,270	—	—	—	—	6,270
Michigan	—	—	241,055	—	—	—	—	241,055
Missouri	—	—	—	49,131	—	—	—	49,131
Montana	4,100	1,715,386	8,274,951	301,158	24,743	35,861	—	10,356,199
Nevada	2,013	8,953,654	29,321	482,018	41,458	—	—	9,508,464
New Mexico	153	364,335	24,768	14,870	918	—	—	405,044
Nort Carolina	114	1,146	—	—	—	—	—	1,260
Oregon	5,851	37,464	287	—	—	—	—	43,602
South Carolina	10	65	151	—	—	—	—	226
South Dakota	179	245,083	—	3,500	—	—	—	248,762
Tennessee	—	—	57,696	—	—	—	—	57,696
Texas	—	435,163	—	9,173	—	—	—	444,336
Utah	63	163,285	2,620,680	5,570,548	86,132	1,044	9,586	8,451,338
Virginia	3	21	93	119	—	—	—	236
Washington	392	59,794	19,211	9,426	—	—	—	88,823
Wyoming	8	—	3,990	—	—	—	—	3,998
	159,285	19,862,038	14,945,189	14,049,481	1,099,283	37,605	722,906	50,875,787
Per cent of total	.3	39.1	29.4	29.7		1.5		

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[1] Philippines and Porto Rico not included in above table.

Gold and Silver Reserves. — Lindgren has pointed out (13) that the gold reserves of the United States are large, but that it is difficult to estimate them with any degree of exactness, a rough estimate even being possible only in the case of placers, which are found chiefly in California and Alaska. These are estimated to contain perhaps $1,000,000,000 of gold in reserve, and the output from this source will probably not decrease for some time. The gold derived from copper ores is not large ($4,800,000 in 1908), but is a stable and increasing quantity, likely to last for 25 years at least. That derived from lead ores is much less, and a slow decrease may be expected.

The quartzose ores form an important source, likely to continue active and strong producers. The United States gold production is not likely to rise above $110,000,000, nor is it likely to sink below $60,000,000 for a long time. Owing to the low price of silver, a number of mines producing ore of this metal have shut down, but the increasing amount supplied as a by-product from lead and copper ores has kept the output steady. The present supply is regarded as assured as long as the mining of lead and copper ores, as well as quartzose gold ores, continues on the present scale.

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CHAPTER XX

MINOR METALS

ALUMINUM — MANGANESE — MERCURY

ALUMINUM

Ores. — This is one of the few metals whose ores do not present a metallic appearance. Many different minerals contain aluminum, but it can be profitably extracted from only a few. Common clay, for example, presents an inexhaustible supply, but the chemical combination of the aluminum in it is such that its extraction up to the present time has not been found practicable.

The ore minerals of aluminum, together with the percentage of the metal which they contain, are: *Corundum,* Al_2O_3 (53.3 per cent); *Cryolite,* AlF_3, 3 NaF (12.8 per cent); *Bauxite,* Al_2O_3, 2 H_2O (39.13 per cent); *Gibbsite,* Al_2O_3, 3 H_2O (34.6 per cent). Of these, corundum is too valuable as an abrasive, and is not found in sufficient quantity to permit its use as an ore of aluminum. Until the discovery of bauxite, cryolite was the chief source of the metal, all of it being obtained from Greenland (10).

Bauxite derives its name from Baux in southern France, where it was first discovered, but in recent years large deposits have been found in the United States. It is usually pisolitic in structure, and may sometimes resemble clay in appearance. The common impurities are silica, iron oxide, and titanic acid; and the variation in the amount of these ingredients can be seen from the following analyses (page 517) of both domestic and foreign occurrences.

Distribution of Bauxite in the United States. — Bauxite in commercial quantity is known to occur in but five districts in the United States. These are the Georgia-Alabama district, the Arkansas district, Wilkinson County, Georgia, near Chattanooga, Tennessee, and a small area in southwestern New Mexico.

Georgia-Alabama (5, 8, 9). — The bauxite deposits of these two states form a belt about 60 miles long, extending from Jacksonville, Alabama, to Cartersville, Georgia (Fig. 224). The ore, which is

Analyses of Bauxite

	1	2	3	4	5	6	7	8
Alumina (Al_2O_3)	57.60	61.89	63.16	59.22	61.00	62.05	62.46	39.92
Ferric oxide (Fe_2O_3)	25.30	1.96	23.55	3.16	2.20	1.66	.81	16.84
Silica (SiO_2)	2.80	6.01	4.15	3.30	2.10	2.00	4.72	20.00
Lime carbonate ($CaCO_3$)	.40	—	—	—	—	—	—	—
Titanic acid (TiO_2)	3.10	—	—	3.62	—	—	.23	1.47
Water (H_2O)	10.80	27.82	8.34	28.80	31.58	30.31	31.03	19.52
Moisture	—	—	—	1.90	3.12	3.50	—	1.25
Alkalies (Na_2O, K_2O)	—	—	.79	—	—	—	—	—

1. Baux, France. 2. Glenravel, Ireland. 3. Wochein, Germany. 4. Georgia. 5. Rock Run, Alabama. 6. Arkansas. 7 and 8. Wilkinson County, Georgia.

It should be stated that all of these, except Nos. 3 and 8, represent good grades of ore, but that within any one district, or even in the same deposit, there may be considerable variation in composition.

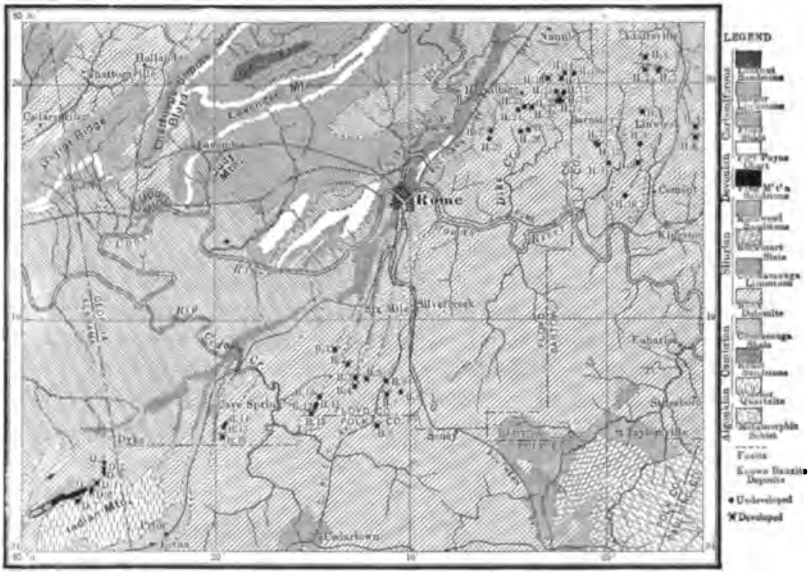

Fig. 224. — Geologic map of Alabama-Georgia bauxite region. (*After Hayes, U. S. Geol. Surv., 16th Ann. Rept., III.*)

either pisolitic or claylike in its character, forms pockets or lenses of variable diameter and depth, in the residual clay derived from the Knox dolomite (Fig. 225 and Pl. LVI). A pronounced feature is their occurrence close to 900 feet above sea level, few being found above 950 feet or below 850 (5).

The bauxite is believed by Hayes (5) to be a hot-spring deposit. It is underlain by the Knox dolomite, and this in turn by the Connasauga shales, which are several thousand feet in thickness, and contain from 15 to 20 per cent of alumina and also pyrite. The region is one of marked faulting. Alteration of the pyrite by percolating meteoric waters has yielded sulphuric acid, which attacked the alumina of the shale, with the formation of alum and also ferrous sulphate. Both of these have been carried toward the surface by spring waters, but since they had to pass through the higher-lying limestones, the lime carbonate acted on the dissolved alum according to the following equation:[1] —

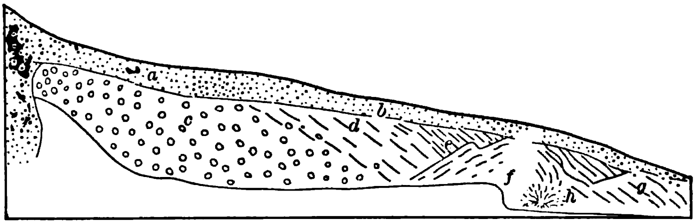

FIG. 225. — Section of bauxite deposit. (*a*) Residual mantle; (*b*) Red sandy clay soil; (*c*) Pisolitic ore; (*d*) Bauxite with clay; (*e*) Clay with bauxite; (*f*) Talus; (*g*) Mottled clay; (*h*) Drainage ditch. (*After Hayes.*)

$$Al_2(SO_4)_3 + 3\,CaCO_3 = Al_2O_3 + 3\,CaSO_4 + 3\,CO_2.$$

The alumina thus formed was a light, gelatinous precipitate, which was carried upward into spring basins on the surface, where it finally settled. The pisolitic structure is thought to have been caused by the balling together of the gelatinous mass by currents.

The Georgia-Alabama deposits, which represent a unique type of occurrence, were discovered in 1887, and have been worked steadily since that time. There have been some misgivings regarding the exhaustibility of the domestic supply, but the discovery and development of extensive deposits in Arkansas have allayed these fears.

Arkansas (2, 4). — The occurrence of bauxite in Arkansas has has been known since 1891, but owing to a more accessible eastern supply, there was little development in that region until 1900. The deposits, which are much more extensive than the Georgia-Alabama ones, are confined to a small area in Pulaski and Saline counties, north and southwest of Little Rock. They have an average thickness of 10 to 15 feet, and show two distinct types. In the southwesterly or Bryant district the lower beds show a granitic structure, and rest directly on a mass of kaolin derived from the elæolite-syenite, and it is probable that the bauxite has also been derived directly from this rock. The upper beds are pisolitic and similar in character to the Georgia-Alabama ones. In the Fourche Mountain area only the pisolitic form is found. The granitic type is the purest, and corresponds in composition to the formula of gibbsite rather than bauxite, while the white bauxitic kaolins run high in silica.

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[1] For clearness, the water combined with the alumina is left out.

The origin of the Arkansas bauxites is somewhat obscure, but Hayes (4) considers that subsequent to the intrusion of the syenite into the palæozoics of that region, the former was exposed by erosion of the latter. This was followed by a submergence of the surface below a body of salt or highly alkaline waters, which in some way penetrated the still partially hot syenite, and dissolved its minerals. On returning to the surface they attacked the syenite there, removing silica and alkalies, and depositing alumina in its place. Much of the alumina was also deposited from these waters as a gelatinous precipitate on the ocean bottom, over the syenite surface. Some was also deposited with the Tertiary sediments then forming.

Wilkinson County, Georgia (7). — This new bauxite-producing area lies near the margin of the Coastal Plain, about 30 miles east of Macon. The bauxite deposits, which occur apparently near the contact of the Tuscaloosa (Lower Cretaceous) and Claiborne (Tertiary) formations, form beds up to 10 feet in thickness, and the ore is generally either pisolitic or concretionary, but some forms exhibit an amorphous character and even flinty appearance. The color varies from white or cream to bright red. Analyses are given above.

The origin of the bauxite is a somewhat obscure problem, and as the field is but little developed, evidence is difficult to secure. Veatch points out, however, that all stages of transition from the clay to the bauxite can be observed, and suggests that the latter has been formed by a desilification of the kaolinite in the clay by circulating meteoric waters carrying some chemical that was capable of abstracting the silica from the hydrous aluminum silicate.

Tennessee Field. — Recently discovered deposits of bauxite on the southeast slope of Missionary Ridge, near Chattanooga, were worked for the first time in 1907. These deposits are of the same character as those found in the Georgia-Alabama field, and may be regarded as a northward extension of that region.

Other Occurrences. — Bauxite is known to occur in Botetourt County, Virginia, in residual clays with iron and manganese ores, but the deposits have not yet proven to be of commercial value (3). Deposits are also known near Silver City, New Mexico (1), and appear to have been derived from a basic volcanic rock by decomposition and alteration in place. Owing to their remoteness from the railroad, they are of little commercial importance.

Uses of Aluminum. — The chief use of this metal is for making wire for the transmission of electric currents, but a large quantity of it is also used in the manufacture of articles for domestic or culinary use, instruments, boats, and other articles where lightness is wanted. It is also employed in the manufacture of special alloys, among which may be mentioned magnalium, an alloy of aluminum and magnesium; and wolframinium, a tungsten-aluminum alloy. One alloy of this type, known as partinium, is said to have a tensile strength of over 49,000 pounds per square inch; McAdamite, an alloy of aluminum, zinc, and copper, is said to possess a tensile strength exceeding 44,000 pounds per square inch;] aluminum silver is an alloy of copper, nickel, zinc, and aluminum; aluminum zinc includes a series of alloys containing various proportions of these two metals. Another extending application is that of powdered aluminum for the production of intense heat by combustion, and in this connection it is used for welding tramway rails, or for the reduction of rare metals from their oxides. A small amount of aluminum added to steel prevents air holes and cracks in casting, and it is also used to clear molten iron and steel of all oxides before casting.

Uses of Bauxite. — The most important use of bauxite is for the manufacture of aluminum, most of the Arkansas production being employed for this purpose. A second important application is for the manufacture of aluminum salts, most of the Georgia-Alabama product being sold for this purpose because of its freedom from iron oxide.

Alundum (artificial corundum) is made from bauxite in the electric furnace. Attempts have been made in recent years to utilize bauxite for bauxite brick,[1] and several firms in this country have begun their manufacture on a small scale, but the demand for them appears to be slight, partly on account of their high price. Bricks of this character are claimed to be of value for basic open-hearth steel furnaces, because of their resistance to the corrosive action of molten metal. They can also be used for lining rotary Portland cement kilns.

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[1] Aubrey, Min. Indus., XIV, 48, 1909.

Production of Bauxite. — The production of bauxite in the United States has been as follows: —

PRODUCTION OF BAUXITE IN THE UNITED STATES, 1889–1908, BY STATES, IN LONG TONS

YEAR	GEORGIA	ALABAMA	ARKANSAS	TOTAL	VALUE
1889	728	—	—	728	$2,366
1890	1,844	—	—	1,844	6,012
1895	8,756	13,313	—	17,069	44,000
1900	19,739		3,445	23,184	89,676
1904	21,913		25,748	47,661	235,704
1905	15,173		32,956	48,129	240,292
1906	25,065		50,267	75,332	368,311
1907	—		—	[1] 97,776	480,330
1908	14,464		[1] 37,703	52,167	263,689

[1] Production of Tennessee included.

The following table shows the annual production, imports, consumption, and value of bauxite in the United States during the last five years: —

PRODUCTION, IMPORTS, AND CONSUMPTION OF BAUXITE IN UNITED STATES, 1904–1908, IN LONG TONS

YEAR	PRODUCTION		IMPORTS		CONSUMPTION	
	Quantity	Value	Quantity	Value	Quantity	Value
1904	47,661	$235,704	15,374	$49,257	63,035	$285,961
1905	48,129	240,292	11,726	46,517	59,855	286,809
1906	75,332	368,311	17,809	63,221	93,141	431,532
1907	97,776	480,330	25,066	93,208	122,842	573,538
1908	52,167	263,968	21,679	87,823	73,846	351,791

The above figures indicate a notable increase in the quantity of imported bauxite, most of which comes from France, and this country was the chief foreign competitor of the American bauxite industry in 1908.

World's Production. — The following table shows the world's production of bauxite from 1905 to 1907, inclusive: —

WORLD'S PRODUCTION OF BAUXITE, 1905–1907, IN LONG TONS

COUNTRY	1905		1906		1907	
	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE
United States . .	48,129	$240,292	75,332	$368,311	97,776	$480,330
France	101,378	205,738	115,926	229,952	155,512	318,206
United Kingdom .	7,300	8,880	6,654	13,274	7,480	9,168
Total . . .	156,807	$454,910	197,912	$611,537	260,768	$807,704

The production of aluminum in the United States since **1883** has been as follows: —

PRODUCTION OF ALUMINUM IN THE UNITED STATES

YEAR	QUANTITY POUNDS	YEAR	QUANTITY POUNDS
1883	83	1904	[1] 8,600,000
1885	283	1905	[1] 11,347,000
1890	61,281	1906	[1] 14,910,000
1895	920,000	1907	[1] 17,211,000
1900	7,150,000	1908	[1] 11,152,000

[1] Consumption.

REFERENCES ON ALUMINUM AND BAUXITE

1. Blake, Amer. Inst. Min. Engrs., Trans. XXIV: 571, 1895. (N. Mex.) 2. Branner, Jour. Geol., V: 263, 1897. (Ark.) 3. Harder, U. S. Geol. Surv., Min. Res. 1908: 699, 1909. (Va.) 4. Hayes, U. S. Geol. Surv., 21st Ann. Rept., III: 435, 1901. (Ark.) 5. Hayes, U. S. Geol. Surv., 16th Ann. Rept., III: 547, 1895. (Ga., Ala.) 6. Laur, Amer. Inst. Min. Engrs., Trans. XXIV: 234, 1895. (The bauxites.) 7. Veatch, Ga. Geol. Surv., Bull. 18: 430, 1909. (Wilkinson Co., Ga.) 8. Watson, Amer. Geol., XXVIII: 25, 1901. (Ga.) 9. Watson, Ga. Geol. Surv., Bull. 11, 1904. (Ga.) 10. For cryolite, see Min. Indus., VI: 251, 1897.

MANGANESE

Ore Minerals and Ores. — While many different minerals contain this metal, practically the only ones of commercial value are the oxides and carbonates, and in this country only the former. The silicates are not used as a source of manganese, owing to their high silica percentage.

The important ore minerals of manganese are the following: *Pyrolusite,* the black oxide (MnO_2, 63.2 per cent Mn); *Psilomelane* (chiefly MnO_2, H_2O; K and Ba variable, 45 to 60 per cent Mn.); *Braunite* ($3\ Mn_2O_3$, $MnSiO_3$, 69.68 per cent Mn); *Wad,* a low-grade earthy brown or black ore, with the percentage of manganese varying from 15 to 40 per cent Mn); *Manganite* (Mn_2O_3, H_2O; 62.4 per cent Mn.); *Rhodochrosite* ($MnCO_3$ 61.7 per cent MnO).

The manganese ores proper consist usually of a mixture of oxides, and indeed these compounds are really the only ones of importance in the United States. Pyrolusite and psilomelane are by far the most important, and are often intimately associated, the pyrolusite generally assuming a crystalline and the psilomelane a massive structure. They may locally have some admixtures of iron oxide, and then they are of use in the steel industry, but when free from iron they are, in addition, of value for oxidizing and coloring purposes. Wad is often of too low grade, due to impurities, to be used as an ore of manganese, but it is sometimes employed for paint. Rhodochrosite, though found as a common gangue mineral in some western mines (Rico, Colorado; Butte, Montana, silver mines), can hardly be regarded as a source of manganese.

Manganese oxides, in addition to being associated with iron, as noted above, are sometimes mixed with zinc or silver. It is customary, therefore, to make a fourfold division into (1) manganese ores, (2) manganiferous iron ore, (3) manganiferous silver ore, and (4) manganiferous zinc residuum.

Manganiferous iron ores found in the United States consist chiefly of limonite or hematite mixed with psilomelane, pyrolusite, or wad, the mixture sometimes being an intimate one, or at others the iron and manganese occurring in the same deposit, but more or less distinct from each other. The high-grade ores are of value for making spiegeleisen or ferro-manganese, but in those running low in manganese this element is usually regarded as an impurity.

Manganiferous silver ores are composed of a mixture of manganese and iron oxides, containing small amounts of silver minerals, lead carbonate, and sometimes even gold. In this class of ores, in which the iron usually predominates over manganese, the ores form the gossan of metallic sulphide bodies carrying iron, lead, zinc, and silver sulphides in a quartz or calcite gangue. Rhodonite and rhodochrosite sometimes occur in the unaltered ores.

This class of ores may be divided into three classes (4) according to their uses as follows: (1) ores used mainly for their silver and lead values, the manganese and iron content sometimes insuring a higher price because of their fluxing action; (2) ores too low in silver and lead to serve as sources of these metals, but sufficiently high in iron and manganese to be employed in making ferro-manganese and spiegeleisen. If too low in manganese, it may be used as an iron ore; (3) ores too low in silver and lead to be used as sources of these metals, and too low in iron and manganese to serve for alloys of these two; such ore is sold for flux, and the lead-silver content ultimately saved.

Manganiferous zinc residuum is obtained from zinc volatilizing and oxidizing furnaces using New Jersey zinc ores, and consists largely of the iron and manganese oxide which remains after the zinc has been volatilized and collected as zinc oxide. The minerals present in the ore are franklinite, zincite, and willemite.

Origin (7, 2). — Manganese oxide deposits are usually of secondary origin, having been formed by weathering processes, which caused the decay of the parent rock containing manganiferous silicates, and the change of these latter to oxides. By circulating ground water they have often been concentrated in residual clays. Although iron also may have been present in the parent rock, and the two are sometimes deposited together, still they have in many instances been separated from each other, due to the fact that conditions favorable for precipitation are not the same for both, or because the soluble compounds of manganese formed by weathering are sometimes more stable than corresponding iron compounds, and hence may be carried farther by circulating waters before they are deposited.

Distribution of Manganese-bearing Ores in the United States. — Although the manganese-bearing ores are widely distributed in the United States, only a few localities are of commercial importance, and the manganese-mining industry has been shrinking for several years.

The reason for this is that the domestic ores are of much lower grade than the imported ones, and often require washing and sorting to render them marketable. Moreover, they occur in small, scattered pockets, often remote from lines of transportation, and may carry a high percentage of phosphorus and silica.

The demand is therefore supplied largely by high-grade ores from India, Brazil, Cuba, and the East Indies.

The occurrence of the four classes of domestic ores may be referred to separately.

Manganese Ores. — The most important regions of this somewhat widely scattered type of ore are the Appalachian and Piedmont regions, southern Mississippi Valley, and Pacific coast, but the chief producing districts have been the James River Valley and Blue Ridge regions in Virginia; Cave Springs and Cartersville districts in Georgia; Batesville district, Arkansas; and the Livermore-Tesla district in California.

Eastern Area. — Manganese deposits are found in the Atlantic states from Vermont to Alabama, and two states in this belt, Georgia and Virginia, lead in the domestic production. The common mode of occurrence is as nodules or lumps in residual clay, similar to the limonites found in the same area.

Virginia (12, 4). — This state has two areas, viz. the James River area in the Piedmont Region, and the Appalachian Valley area.

The ore of the Piedmont region is found in the James River Valley, northeast and south of Lynchburg. The deposits occur in residual clay and sand which have been derived from crystalline rocks, and the ore occurs in nodular masses up to 500 pounds weight, which are scattered through a yellowish brown micaceous clay that forms a nearly vertical layer between decomposed granite and residual material derived from quartzose mica schist. A manganese stained clay known as " umber," formed possibly from crystalline limestone, is associated with many of the Piedmont manganese deposits.

The Appalachian Valley deposits occur in two districts, viz. the Blue Ridge and New River.

The ores of the first district, which are the most important of the two, occur in a series of irregularly distributed deposits along the west foot of the Blue Ridge from Front Royal to Roanoke, a distance of about 150 miles. This same belt includes the Blue Ridge iron-ore deposits, which may sometimes contain an appreciable amount of manganese. So, too, iron may be found in the manganese deposits.

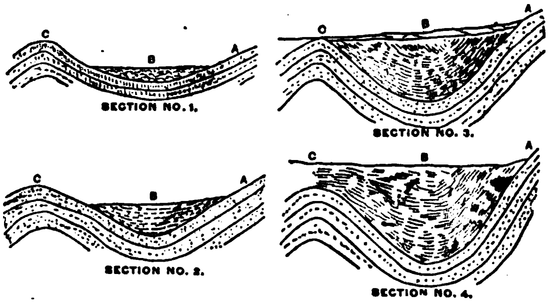

FIG. 226. — Sections of Manganese deposit, Crimora, Va. (*After Hall.*)

The manganese ore occurs in pockets in clays of residual or sedimentary character, along the contact of the Lower Cambrian quartzite with the overlying formation, and more rarely in fissures penetrating the quartzite.

Four types of ore are found, all of which may occur in the same deposit. They are: (1) black psilomelane kidneys in clay; (2) irregular, often porous masses of psilomelane with layers of crystalline pyrolusite, also in clay; (3) breccia ore in large masses consisting of sandstone or chert fragments, with pyrolusite or psilomelane filling; (4) replacements or cavity fillings, mainly pyrolusite, in sandstone or sandy clay. The mine at Crimora (Fig. 226) is one of the best known. The ore forms pockets 5 to 6 feet thick, and 20 to 30 feet long in a deposit of clay 276 feet thick.

In the New River district, the ore which is mainly psilomelane occurs as large masses mixed with iron ores in residual clay, but is of little commercial importance.

The Virginia areas mentioned extend southward into Tennessee, and some ore is mined there.

Georgia. — In northern Georgia (5, 11) the ore results from the decay of limestones and shales, Cave Spring and Cartersville being important localities (Fig. 227). The deposits are found in the areas underlain by both the crystalline and Palæozoic rocks, but only those associated with the latter have proven to be of importance. In this region the rocks consist of Cambro-Silurian limestones and quartzites, which have been much folded and faulted, and have been weathered down to a residual clay, which is often not less than 100 feet thick. The ore occurs as pockets, lenticular masses, stringers, grains, or lumps, irregularly scattered through the clay, and rarely forming distinct beds. None of the deposits are large, though some 30 feet in length have been worked. More or less limonite, barite, ocher, and bauxite may be associated with the ore (Fig. 228), and, indeed, complete gradations from manganese to iron ore are found, as shown by the following analyses: —

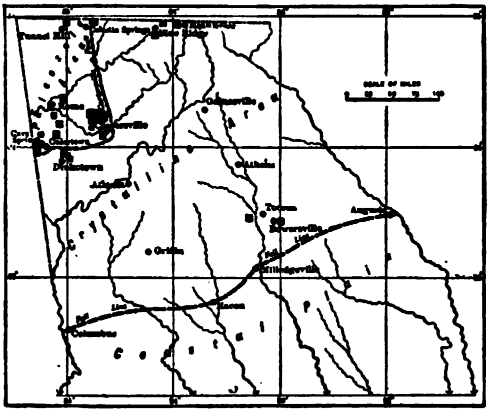

FIG. 227. — Map showing Georgia manganese areas. (*After Watson, Amer. Inst. Min. Engrs., Trans. XXXIV.*)

Mn	60.61	54.94	41.98	15.26	2.30
Fe	1.45	3.62	16.22	39.25	52.02
P	.052	.034	.227	.193	.24

The better-grade ores are usually low in silica, iron, and phosphorus. In the Cartersville district, which is the more important, the ore is found in residual clays derived from the Beaver limestone and Weisner quartzite, while in the Cave Spring area it occur only in the clays overlying the Knox dolomite.

Penrose (8) thought that the manganese was derived from the underlying Cambro-Silurian sediments, while Watson, on the contrary, believes that the crystalline rocks to the east and south have

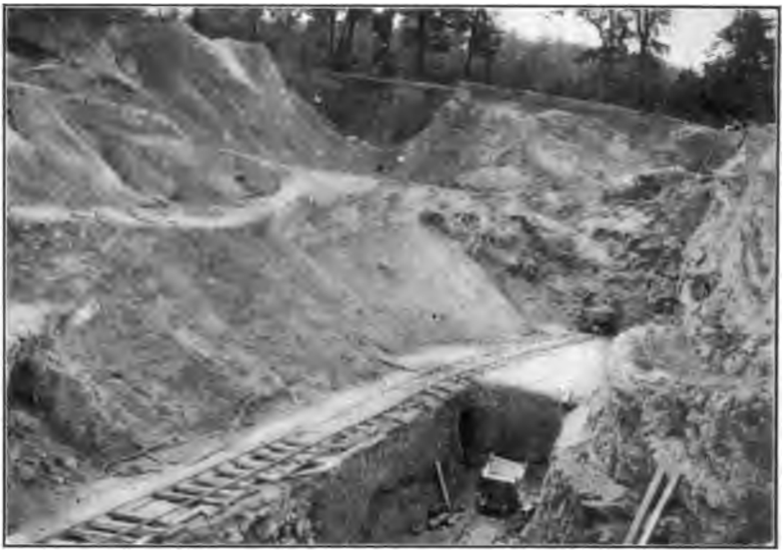

FIG. 1. — View of bauxite bank, Rock Run, Ala. (*H. Ries, photo.*)

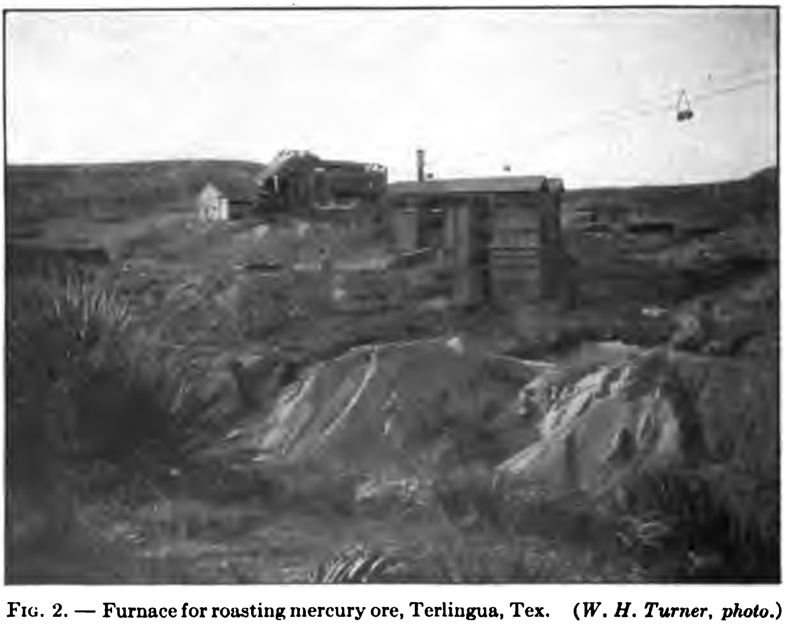

FIG. 2. — Furnace for roasting mercury ore, Terlingua, Tex. (*W. H. Turner, photo.*)

furnished the ore, as none is found in the parent rock from which the clays were derived. The manganese was probably taken into solution as a sulphate, and concentrated by circulating waters of meteoric origin in the residual clays where now found.

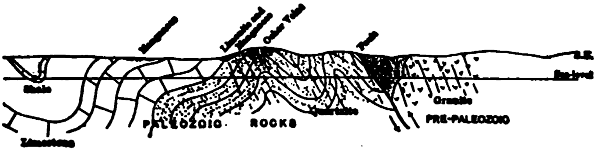

FIG. 228. — Section in Georgia manganese area, showing geologic relations of manganese, limonite, and ocher. (*After Watson, Amer. Inst. Min. Engrs., Trans. XXXIV.*)

The Georgia (10) deposits have been worked for a number of years, and the manganese was formerly marketed chiefly in England; but the output is now sold entirely in the United States. The ore, which has to be purified by washing and crushing, is used in part for paint and in part for steel manufacture.

Other Eastern Occurrences. — Deposits are known at several localities in Vermont (8), North Carolina, (4) South Carolina (4), and Pennsylvania (4).

Lower Mississippi Valley and Gulf Region. — The Arkansas deposits are the only important ones in this region.

Arkansas. — Manganese ore is found in the region around Batesville (8, 9), associated with horizontally stratified limestones and shales, ranging from Ordovician to Carboniferous Age (Fig. 229).

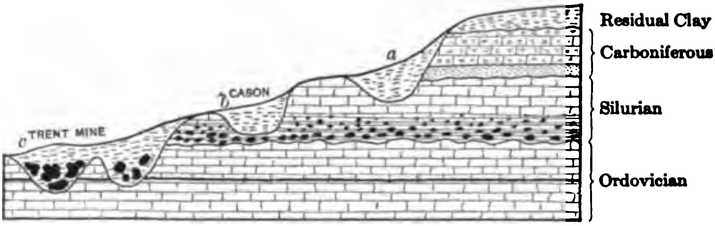

FIG. 229. — Section in Batesville, Ark., manganese region, illustrating geological structure and relation of different formations to marketable and non-marketable ore. (*After Van Ingen, Sch. of M. Quart., XXII.*)

The Cason shale, of Silurian Age, occurring near the middle of the section (Fig. 229 *b*), carries manganese nodules high in phosphorus, which are not marketable, and others are found in the pits of residual clay derived from it. Farther down the slopes marketable ore (Fig. 229 *c*), which has been derived by leaching of the first-mentioned ore, is found occurring in residual pockets in the lower-lying limestones, while the residual clays (Fig. 229 *a*), formed at a higher level than the Cason shale, are barren of manganese.

Other Occurrences. — Small deposits are said to occur in Hickman County, Tennessee, and Llano County, Texas.

Western States. — Two types of ore are found in California. The first of these consist of veins of pyrolusite, and psilomelane in the Calaveras (Carboniferous) formation, occurring near Meadow Valley, Plumas County, and at other points in the Sierra Nevada. The second occurs near the coast north and south of San Francisco, as local thin lenses, interbedded with jaspers of the Franciscan (Jura-Trias) formation. At the Ladd mine near Livermore, the ore lies in a fault fissure, 4 to 5 feet in width, and forms cavity fillings, infiltrations, and replacement deposits in red and yellow clays, and as veins and breccia cement in the wall. The wall rock is jasper (4).

Small deposits are also known in Utah where, in Grand County, the ore occurs as replacements in Triassic limestone (6), and near Golconda, Nevada. The latter, which is bedded, and is interstratified with calcareous and siliceous tufa, appears to be a hot-spring deposit in a small tufa basin.

Manganiferous Iron Ores. — Those of the Appalachian Valley have already been referred to in connection with the manganese ores. The most important deposits are in Vermont, Virginia, and Tennessee, and consist chiefly of psilomelane and limonite mixtures. Much iron ore of the Lake Superior district carries from 1 to 10 per cent metallic manganese. It usually occurs in small patches mixed with hematite. Other occurrences have been noted from Gunnison County, Colorado (6), Juab County, Utah, and Missouri, but they are not of commercial value.

Manganiferous Silver Ores. — The most important deposits are those found at Leadville, Colorado. They occur as replacements of the blue Carboniferous limestone near its contact with the porphyry, and consist of a black mixture of manganese and iron oxides with lead carbonate and silver, the manganese content ranging from 10 to 40 per cent. In the underlying sulphides the manganese is absent and the large quantity in the oxidized ore is believed to represent an infiltration from the porphyry (2). This ore is used both in the steel industry and for fluxing. Ores of similar character are found at Neihart and Castle, Montana. Manganese is also found in the silver veins at Butte, Montana, but is of little commercial value. Still other manganiferous silver ores have been noted from scattered localities in New Mexico, Arizona, Utah, and Nevada, but appear to be of little commercial importance. Some found in the Tintic district, Utah, are used as flux at the local smelters.

Uses of Manganese. — Manganese is used in the manufacture of alloys, whose value depends not only on the amount of manganese, but also on the absence of sulphur and phosphorus. Spiegeleisen contains under 20 per cent manganese, and ferromanganese, a similar alloy, has from 20 to 90 per cent of it. The amount of silicon and carbon present in these varies.

Other alloys are manganese bronze, manganese and copper, with or without iron. Some alloys of manganese, aluminum, and copper, known as Heusler's alloys, are important because of their magnetic properties. Other elements alloying with manganese are zinc, tin, lead, magnesium, and silicon.

Manganese oxide is used: (1) as a substitute for iron oxide in copper and silver reduction; (2) as an oxidizing agent in the manufacture of chlorine, bromine, and disinfectants; (3) as a decolorizer of green glass; (4) as a coloring agent in calico printing and dyeing, in the making of glass, pottery, bricks, and also paints; (5) in the manufacture of the Leclanché battery and of dry cells, for which purpose a considerable amount is consumed annually.

Some manganese compounds have a medicinal value, and rhodonite is sometimes cut for a gem stone.

Production of Manganese. — Although much used in steel manufacture, the domestic production is small because of the inferior character of the native ores, therefore the largest consumers rely upon foreign sources of supply.

The following table gives the total quantity of the several kinds of ore produced in the United States. The annual production since 1885 is given because the output has fluctuated so. The strong decline in the production of the straight manganese ores is well brought out.

PRODUCTION OF MANGANESE ORES IN THE UNITED STATES, 1885 TO 1908, IN LONG TONS

	MANGANESE	MANGANIFEROUS IRON ORE	MANGANIFEROUS SILVER ORE	MANGANIFEROUS ZINC RESIDUUM
1885	23,258	——	4,263	——
1886	30,193	257,000	60,000	——
1887	34,524	211,025	60,726	——
1888	29,198	202,132	60,000	——
1889	24,197	81,359	64,987	43,648
1890	19,287	61,863	58,237	48,560
1891	22,452	132,511	80,475	38,228
1892	13,613	150,431	65,251	31,859
1893	7,718	112,016	61,728	37,512
1894	6,308	198,466	38,709	26,981
1895	9,547	112,265	67,627	43,249
1896	10,088	329,640	147,151	44,935
1897	11,108	185,705	166,014	33,924
1898	15,957	268,962	118,199	48,502
1899	9,935	732,490	109,210	65,010
1900	11,771	334,274	231,812	87,110
1901	11,995	512,104	291,572	52,311
1902	7,477	887,939	207,407	65,246
1903	2,825	569,637	194,061	73,264
1904	3,146	366,172	122,352	68,189
1905	4,118	723,419	127,575	90,289
1906	6,921	1,008,900	32,400[1]	93,461
1907	5,624	318,449	99,711	93,413
1908	6,144	471,480	51,554	110,225

[1] Returns incomplete.

PRODUCTION OF MANGANESE ORE IN THE UNITED STATES, 1906–1908, BY STATES, IN LONG TONS

STATE	1906			1907			1908		
	QUANTITY	VALUE	AVERAGE PRICE PER TON	QUANTITY	VALUE	AVERAGE PRICE PER TON	QUANTITY	VALUE	AVERAGE PRICE PER TON
Arkansas . . .	62	$290	$4.68	—	—	—	—	—	—
California . . .	1	20	20.00	100	$600	$6.00	—	—	—
South Carolina .	—	—	—	800	4,800	6.00	—	—	—
Tennessee . . .	30	300	10.00	100	1,500	15.00	—	—	—
Utah	800	10,000	12.50	—	—	—	—	—	—
Virginia . . .	6,028	77,522	12.86	4,604	56,469	12.27	6,144	$62,779	$10.22
	6,921	$88,132	$12.73	5,604	$63,369	$11.31	6,144	$62,779	$10.22

The average price per long ton for Colorado manganiferous silver ores in 1908, was $2.48, and of manganiferous zinc residuum, $2.05. The prices of manganese ores used in the steel industry vary from $5 to $15 per long ton, according to grade.

They are governed by the following schedule of prices established by the Carnegie Steel Company, the price being for delivery at Pittsburg or South Chicago.

Prices are based on ores containing not more than 8 per cent silica or .25 per cent phosphorus, and are subject to deductions as follows: For each 1 per cent in excess of 8 per cent silica there shall be deduction of 15 cents per ton; fractions in proportion.

For each .02 per cent, or fraction thereof, in excess of .25 per cent phosphorus, there shall be a deduction of 2 cents per unit of manganese per ton.

Percentage of Metallic Manganese in Ore	Price per Unit, in Cents	
	Manganese	Iron
Over 49	30	6
46 to 49	29	6
43 to 46	28	6
40 to 43	27	6

Ores containing less than 40 per cent manganese or more than 12 per cent silica or .27 per cent phosphorus are subject to acceptance or refusal at the buyer's option.

Settlements are based on analysis of sample dried at 212° F., the percentage of moisture in the sample as taken being deducted from the weight.

The manganese ores for oxidizing and coloring purposes are valued according to the quantity of manganese peroxide present, their consistency, etc., and prices range up to $25 per ton for the better grades of ore. Manganiferous ores used in steel manufacture and for fluxing range in price upward from $2 per ton.

The imports in 1907 amounted to 209,021 long tons valued at $1,793,143, and in 1908 to 178,203 long tons valued at $1,350,223.

World's Production. — The following table gives the latest available statistics with regard to the world's production of manganese ore. The unit is either the long or the metric ton, except for Canada, where the short ton is used.

WORLD'S PRODUCTION OF MANGANESE ORES

COUNTRY	YEAR	QUANTITY	COUNTRY	YEAR	QUANTITY
North America:		Tons	Europe — *Continued.*		Tons
United States	1908	6,144	Portugal	1906	22
Cuba	1907	34,171	Russia	1906	1,016,000
South America:			Spain	1906	63,000
Brazil[1]	1905	233,950	Sweden	1907	4,300
Chile	1905	1,324	Turkey[1]	1905	28,600
Europe:			Norway	1904	22
Austria	1907	16,800	Asia:		
Bosnia and Herzegovina	1906	7,651	India	1906	504,000
Hungary	1906	11,000	Japan	1906	13,000
France	1907	18,200	Java	1905	1,600
Germany	1907	75,000	Oceania:		
Greece	1906	10,000	Queensland	1906	1,130
Italy	1907	3,700	New Zealand	1906	16
United Kingdom	1907	16,400			

[1] Exports.

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MERCURY

Ores. — While mercury is sometimes found native in the form of *Quicksilver*, the most common ore is *Cinnabar* (HgS), which contains 86.2 per cent mercury. Native amalgam of mercury and silver is known, and *Calomel*, the chloride, as well as other compounds, are sometimes found.

Mode of Occurrence. — Mercury ores are not confined to any particular formation, but are found in rocks ranging from the Ordovician to Recent Age in different parts of the world. Nor are they peculiar to any special type of rock, although igneous rocks are often found in the vicinity of them. They occur as veins, disseminations, or as masses of irregular form. Silica, either crystalline or opaline, and calcite are common gangue minerals, while pyrite or marcasite are rarely wanting, and bitumen is widespread.

Distribution in the United States. — California has always been the most important, and, in fact, at times, the only producing state. Deposits are, however, also known in Texas, Oregon, Utah, Nevada, and New Mexico.

Origin. — The origin of mercury ores has been studied chiefly by Becker (1) and later by Schrauf (9). The former points out that silica (either crystalline or amorphous) and calcite are common gangue minerals, but pyrite or marcasite are almost equally abundant, as is also bitumen. In addition to these, the ores show an irregular association with other metallic minerals, such as antimony, silver, lead, copper, arsenic, zinc, or even gold. Becker believes that the cinnabar has been precipitated from ascending waters by bituminous matter, having come up in solution as a double sulphide with alkaline sulphides. He further suggests that the deposits represent impregnations and are not replacements.

California (1, 2) (Fig. 230). — The California ores occur chiefly in metamorphosed Cretaceous or Jurassic rocks, with some in the Miocene and even Quaternary. The deposits, which are termed "chambered veins" by Becker, are fissured zones. Eruptive rocks seem in many cases to be involved in the ore formation, and at New Almaden a rhyolite dike runs parallel with the ore body. The ore here occurs along the contact between serpentine and shale, filling in part the interstices of a breccia. These mines, which are the largest in the state, have been worked to a depth of over 2500 feet.

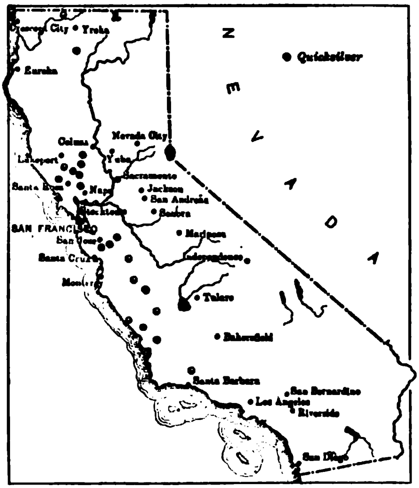

Fig. 230. — Map of California mercury localities.

At the New Idria mine, located in southeastern San Benito County, and which has been worked almost continually since 1853, the ore bodies occur as stockworks in metamorphic rocks of Lower Cretaceous Age, just south of their contact with the unaltered sediments of the Chico (Upper Cretaceous) formation. The ore which is irregularly distributed between a false hanging wall of clay, and a foot wall of shale, consists of a mixture of pyrite and cinnabar, with a gangue of silicified and brecciated metamorphic sandstones and shales. It is interesting to note that in driving a tunnel to connect with the 1060-foot level considerable natural gas was encountered, and that at another locality, New Almaden, exhalations of carbon dioxide were encountered in some of the lower levels.

Other occurrences are in Colusa County, where the cinnabar is found in altered serpentine, and in Napa County, where it occurs along the contact of sandstone and slate. The minerals associated with these are bitumen, free sulphur, stibnite, mispickel, gold and silver, chalcopyrite, pyrite, millerite, quartz, calcite, barite, and borax. The vein is a fissure filled with brecciated fragments, and cuts through sandstone, shale, and augite andesite, the cinnabar cementing the breccia together, but at times also impregnating the walls. Hot waters which circulate through the vein still deposit gelatinous silica.

At Steamboat Springs the waters carry gold, sulphide of arsenic, antimony, and mercury, sulphides or sulphates of silver, lead, copper, zinc, iron oxide, and possibly other metals. They also contain sodium carbonate, sodium chloride, sulphur, and borax.

Cinnabar is known in Lane and Douglas counties, Oregon.

Texas (3, 7, 8, 11). — The Terlingua district of Brewster County, Texas (Fig. 231), has aroused much interest in recent years.

The area of importance is about two miles wide north and south and fifteen miles east and west, and lies in southern Brewster County, about 300 miles southeast of El Paso, and 110 miles south of Marfa. It is 7 miles to the Rio Grande and Mexican border. The remoteness from the railroad and lack of water have formed serious obstacles in the development of the district.

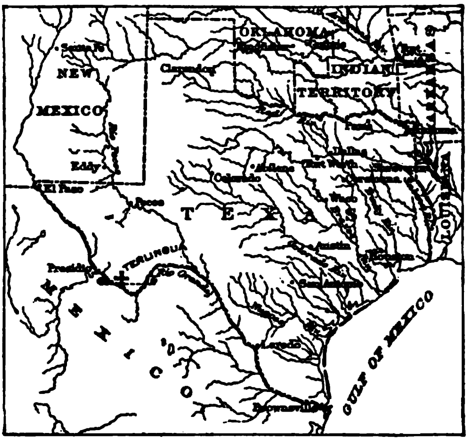

FIG. 231. — Map showing Texas mercury region. (*After Hill, Eng. and Min. Jour., LXXIV.*)

The rocks are sediments of Upper and Lower Cretaceous Age cut by Tertiary volcanics, and the following section is involved:—

Tertiary tuffs and lavas, forming sheets, dikes, laccoliths, and surface flows. The rock types included are andesites, rhyolites, phonolites, and basalts.

Upper Cretaceous.	
Ponderosa marls	200 ft.
Austin chalk	100 ft.
Eagle Ford shales	400 ft.
Lower Cretaceous.	
Vola limestones	75 ft.
Arietina clays or Del Rio shales	75 ft.
Washita or Fort Worth limestone	100 ft.
Fredericksburg or Edwards limestone	1000 ft.

There has been important faulting, the strike of the chief dislocation being northwest-southeast, but that of the ore-filled fissures is northeast-southwest.

The ore bodies have thus far been found chiefly in the Washita and Fredericksburg limestones, but more recently in the Eagle Ford shales. The ore is most frequently found in fissure veins (Fig. 233), but some occurs in breccias and as lateral-enrichment deposits.

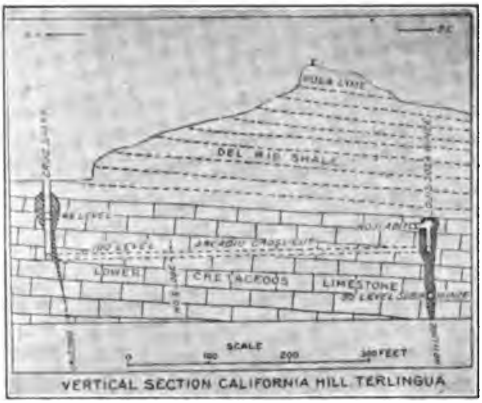
DEL RIO SHALE
ARCADIO CROSS-CUT
LOWER CRETACEOUS LIMESTONE
SCALE
0
100
200
300 FEET
VERTICAL SECTION CALIFORNIA HILL TERLINGUA

FIG. 232. — Vertical section of California Hill, Terlingua, Tex. (*After Turner, Econ. Geol., I.*)

The chief ore mineral is cinnabar, which is often closely associated with pyrite or its oxidation products, especially in the breccia lodes. Calcite is the most important gangue mineral. Gypsum (probably secondary) is common and hydrocarbons may be present. It is of interest to note that three new minerals, Terlinguaite, Eglestonite, and Montroydite, all oxychlorides of mercury, were discovered in these ores.

The ore treated in the furnaces varies from .75 to 2.5 per cent mercury, while that sent to the retorts runs 4 per cent or over.

Most of the workings are open pits, there being few shafts, so no definite idea of the underground reserves exists.

Uses of Mercury. — The most important use of quicksilver is in the extraction of gold and silver by the process of amalgamation (see Gold and Silver). Its power of forming amalgams with other metals makes it of value in the arts for the preparation of a substance used for silvering mirrors and for other purposes. Because it is liquid at ordinary temperatures it can be employed in the manufacture of thermometers; and this fact, added to its weight, renders it of special value in the construction of mercurial barometers. In medicine mercury is used in various forms, chiefly as calomel, while cinnabar and other compounds of mercury are valuable in the manufacture of pigments.

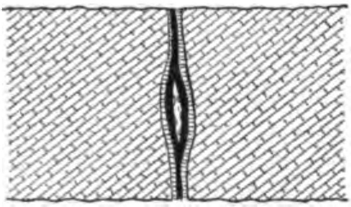

FIG. 233. — Section of cinnabar vein in limestone, Terlingua, Tex. (*After Phillips, Univ. Tex. Min. Surv., Bull. 4.*)

For this purpose it was used by the American Indians and by the other early races of people.

Cinnabar is easily decomposed by heat, giving off when heated in air, or retorted with quicklime, the mercury vapors and sulphur dioxide in one case, or mercury, calcium sulphide, and calcium sulphate in the other.

The mercury is collected by subsequent condensation.

Retorts are adapted only to ores carrying 4 per cent or more of mercury, while low-grade ores are treated in shaft furnaces, some of the more modern ones being capable of treating an ore running as low as .25 per cent metal.

Production of Mercury. — California was for many years practically the only domestic source of mercury, but in 1898 Texas became a producer, and will no doubt continue so. The output of mercury is quoted in flasks of 76½ pounds net. That of California since 1850 has been as follows:—

PRODUCTION OF MERCURY IN CALIFORNIA FROM 1850 TO 1900 IN FLASKS OF 76½ POUNDS

1850	7,723	1900	26,317
1860	10,000	1905	24,635
1870	30,077	1906	20,310
1880	59,926	1907	17,431
1890	22,926	1908	16,984

PRODUCTION OF QUICKSILVER IN THE UNITED STATES IN 1906 AND 1908, IN FLASKS OF 75 POUNDS

STATE	1906		1907		1908	
	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE
Arizona and Oregon[1]	3	$109	——	——	386	$17,170
California	20,310	730,808	17,431	$662,544	16,984	684,716
Texas	4,761	178,829	3,686	148,387	2,382	122,260
Utah	1,164	48,888	450	18,000	——	——
	26,238	$958,634	21,567	$828,931	19,752	$824,146

[1] In 1906 Oregon alone.

The average price per flask in 1907 was $38.43 and in 1908 it was $41.72.

The imports in 1907 amounted to 16,567 pounds, valued at $6719, while those of 1908 amounted to 15,113 pounds, valued at $8216. The exports for 1907 were 5132 flasks, valued at $192,094, while those for 1908 included 2996 flasks, valued at $124,960. The exports went to nearly all parts of the world.

WORLD'S PRODUCTION OF QUICKSILVER, 1907–1908, IN METRIC TONS

COUNTRY	1907	1908
United States	734	672
Austria	610	630
Italy	423	680
Russia	130	49
Spain	1,210	1,065
Mexico	200[1]	200[1]
	3,307	3296

[1] Partly estimated.

REFERENCES ON MERCURY

1. Becker, Geology of Quicksilver Deposits of Pacific Slope, U. S. Geol. Surv., Mon. XIII, 1888. 2. Becker, U. S. Geol. Surv., Min. Res., 1892: 139, 1893. (Origin.) 3. Blake, W. P., Amer. Inst. Min. Engrs., Trans. XXV: 68, 1896. (Cinnabar in Texas.) 4. Forstner, Calif. State Ming. Bur., Bull. 27, 1903, (Calif.) also Eng. and Min. Jour., LXXVIII: 385 and 426, 1904. 5. McCaskey, U. S. Geol. Surv., Min. Res. 1907: 689, 1908. (Very complete bibliography.) 6. Moses, Amer. Jour. Sci., XVI: 253, 1903. (New minerals, Tex.) 7. Phillips, Univ. Tex. Min. Surv., Bull. 4, 1902. (Terlingua district, Texas.) 8. Phillips, Econ. Geol., I: 155, 1905. (Tex.) 9. Schrauf, Zeitsch. prak. Geologie, II: 10, 1894. (Origin.) 10. Stafford, Bull. Univ. Ore., new ser., I, No. 4, 1904. (Ore.) 11. Turner, Econ. Geol., I: 265, 1905. (Tex.)

CHAPTER XXI

MINOR METALS (Continued)

ANTIMONY TO VANADIUM

ANTIMONY

Ore Minerals. — *Stibnite* (Sb_2S_3) is the most important ore of antimony, and the metal is rarely obtained from any other mineral, although native antimony has been sparingly found. The oxide *Senarmontite* (Sb_2O_3) seldom occurs in any quantity. A small amount of antimony is present in some silver-lead ores. The stibnite, together with a gangue of quartz, and sometimes calcite, usually forms veins cutting igneous, sedimentary, or metamorphic rocks.

Distribution of Antimony in United States. — Antimony has been found at a number of localities in the Cordilleran region, but the great distance of the deposits from the railroad, together with the fact that the smelting plants are located in the East, make them of little commercial value, and the domestic production is very small and irregular. Thus in 1908 some ore was mined and sold from Humboldt County, Nevada, and a small quantity was mined at Burke, Idaho, but was not sold.

Many gold and silver ores carry some antimony, and in smelting it combines with the lead, giving a product known as antimonial lead, much of which is produced in the United States.

The large amount of antimony now manufactured in the United States is obtained: (1) as a by-product from the smelting of foreign and domestic lead-silver ores containing small quantities of antimony; (2) antimony regulus, or metal from foreign countries; (3) foreign ore.

Very little has been published regarding the occurrence of antimony ores in the United States. Hess has described some deposits in Arkansas (4), where the antimony occurs as bedded veins in sandstones and shales, with a quartz gangue, and associated with a number of different metallic minerals. The deposits are of doubtful value, except possibly when high market prices prevail.

Along Coyote Creek, in Garfield County, Utah (5), there are found flat-lying deposits of stibnite and its oxidation products in Eocene (Tertiary) sandstone and conglomerates. The ore in sight is all low grade, although some rich pockets have been worked out in the past.

Uses. — Antimony metal is used chiefly in the manufacture of alloys of lead, tin, zinc, etc. Type metal, which is an alloy of lead, antimony, and bismuth, has the property of expanding at the moment of solidification. Britannia metal is tin with 10 to 16 per cent antimony and 3 per cent copper. Babbitt, or antifriction metal consists of antimony and tin, with small amounts of lead, copper, bismuth, zinc, and nickel. Tartar emetic, a potassium-antimony tartrate, antimony fluoride and ammonium sulphide, and other double salts are used in medicine and as a mordant for dyeing, while antimony persulphide is employed for vulcanizing and coloring rubber. Antimony trioxide is employed as a substitute for white lead, zinc oxide, etc., in pigments. It is also used in a glaze for coating enameled iron ware, as a reducing agent in chemical work, and as a detector of alkaloids and phenols. The trichloride is used in bronzing gun barrels, in coloring zinc black, and as a mordant for patent leather and silver. Antimony trisulphide is used in pyrotechnics for making "Bengal fire." Antimony chromate, or "Naples yellow," is used for coloring.

Production of Antimony. — The production of metallic antimony from domestic and foreign ores since 1903 was as follows: —

PRODUCTION OF ANTIMONY IN THE UNITED STATES, 1903–1907, IN SHORT TONS

YEAR	CONTAINED IN ANTIMONIAL LEAD		ANTIMONY PRODUCED FROM FOREIGN AND DOMESTIC ORE	
	Quantity	Value	Quantity	Value
1903	2,558	$445,092	[1] 570	$103,341
1904	2,571	443,598	[2] 486	61,926
1905	2,747	588,354	493	117,433
1906	1,362	[4] 544,800	[3] 404	58,149
1907	(5)	——	[3] 351	77,300
1908	(5)	——	None	None

[1] Exclusive of foreign ores imported and re-exported.

[2] Estimated from the average content of the ore.

[3] Figured as 60 per cent of domestic ores only; direct figures from the smelters could not be obtained.

[4] Estimated from the prices current for the year.

[5] Included under antimonial lead.

In 1906 the price of the best grade of antimony reached 28 cents a pound, and not only stimulated the search for ores of this metal, but started preparations for working some of the known deposits; by the end of 1907 the price had dropped to 9.5 cents, and the western ores could therefore not be profitably operated.

ANTIMONY, ANTIMONY ORE, AND SALTS OF ANTIMONY IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES, 1903–1908, IN POUNDS

YEAR	METAL AND REGULUS		CRUDE ANTIMONY AND ORES		SALTS OF ANTIMONY		TOTAL VALUE
	Quantity	Value	Quantity	Value	Quantity	Value	
1903 . . .	4,694,309	$260,144	2,714,617	$54,316	916,468	$66,469	$380,929
1904 . . .	4,268,045	248,726	2,488,518	50,414	981,026	70,668	369,808
1905 . . .	4,941,247	431,228	1,970,788	53,026	1,010,228	80,130	564,384
1906 . . .	10,305,734	1,391,289	1,972,658	125,841	764,070	99,251	1,616,279
1907 . . .	9,600,901	1,407,861	2,771,387	180,903	682,192	98,038	1,686,802
1908 . . .	8,089,915	771,206	3,287,218	106,930	623,125	65,898	944,034

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ARSENIC

Ore Minerals. — Although arsenic-bearing minerals are widely distributed in many countries, the commercially valuable occurrences are few.

The minerals which may serve as sources of arsenic together with their composition and per cent of arsenic are: *Arsenopyrite* (FeAsS, 46.02); *Löllingite* ($FeAs_2$, 72.8); *Orpiment* (As_2S_3, 60.96); *Realgar* (As_2S_2, 70.08); *Arsenolite* (As_2O_3, 75.8).

Of these the first is the most important, in this country at least.

Distribution in the United States. —Little has been published on the occurrence of arsenic ores in the United States, and indeed there appear to be comparatively few discovered deposits of commercial importance. Many gold, copper, and other ores contain small amounts of arsenic, but in the roasting or smelting of the ore most of this is allowed to pass up the stack. Arsenopyrite has been mined in Washington, where the mineral is used for making arsenious oxide. The ore is said to average about 14 per cent arsenic, .7 ounces gold and 3 ounces silver per ton (2).

In Virginia (4), arsenopyrite has been found at Rewald, Floyd County. The material occurs as a series of lenses in quartz-sericite schist, the principal lens being 3 feet at the surface, but thickening to 14 feet at a depth of 120 feet. In Rockbridge County, in the same state, the arsenopyrite is found in association with pyrite and cassiterite in quartz-greisen-bearing tin veins, but it is not worked.

Arsenopyrite and subordinate pyrite with a quartz gangue, forming a series of parallel stringers in gneiss, close to a basic dike, is found near Carmel, Putnam County, N. Y. (5). The product of the mine when concentrated averages 25 per cent arsenic.

Many of the California gold ores are said to be arsenical, and auriferous sulphides, realgar, and orpiment are mined at Monte Cristo, Washington (Hess).

None of the above-noted occurrences are worked steadily, and in 1908 arsenic was produced commercially at only two localities in the United States. One of these was at Everett, Washington, where arsenic was made from arsenical ores mined in California and Washington, together with flue dust from some Utah and Montana smelters. The other locality was at Anaconda, Montana, where the arsenic was recovered from the flue dust.

Uses of Arsenic. — Arsenopyrite is used chiefly for the manufacture of arsenious oxide. Arsenic is employed in medicine, as a pigment, and as an alloy with lead for making shot. Arsenious oxide is used for making paris green, in glassware for counteracting the iron coloration, in certain enamels, and as a fixing and conveying substance for aniline dyes. Realgar, the disulphide, is used in printing, tanning, and also in pyrotechnics, since it burns with a white light. Orpiment is used as a reducing agent in chemical work. Potassium arsenite is of value as a reducer for silver in the manufacture of mirrors, while the arsenic trioxide is useful for preserving skins.

Production of Arsenic. — The domestic production is not given by the United States Geological Survey for 1908, as there were only two producers. The production and imports from all sources are given on the next page.

Production and Imports of Arsenic, 1906–1908

Year	Production of White Arsenic		Imports			
			White Arsenic, Metallic Arsenic, and Arsenic Sulphides		Paris Green and London Purple	
	Quantity (short tons)	Value	Quantity (short tons)	Value	Quantity (pounds)	Value
1906	737	$63,460	3,987	$350,045	311,293	$21,347
1907	1,751	163,000	5,164	574,998	133,422	21,919
1908	——	——	4,964	430,400	195,000	30,764

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BISMUTH

Ore Minerals. — The principal ores of this metal, together with the percentage of metallic bismuth which they contain, are: *Bismuthinite* (Bi_2S_3, 81.2); *Bismite* (Bi_2O_3, 96.6); and *Bismutite* (Bi_2O_3, CO_2, H_2O, 80.6). Although all of these contain a high percentage of metallic bismuth, the content of the ore as mined does not usually exceed ten or fifteen per cent. Bismuth ores are commonly associated with those of gold and silver, and the metal is obtained as a by-product in the smelting of these.

Distribution. — There are many scattered occurrences of bismuth ores throughout the Rocky Mountain states. Some of the gold ores on Breece Hill near Leadville, Colorado, carry as much as 5 to 8 per cent bismuth,[1] and nearly all of the gold ores at Goldfield, Nevada (*q.v.*), carry this metal, partly in the form of bismuthinite. Other western ores also carry bismuth.

Uses of Bismuth. — Bismuth is chiefly valuable on account of the easily fusible alloys which it forms with lead, tin, and cadmium; the melting point of some of these lies between 64° C. and 94.5° C. They are therefore employed in safety fuses for electrical apparatus, safety plugs for boilers, dental amalgams, and for automatic sprinklers. Several compounds of bismuth are of value in medicine and chemistry.

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[1] George Argall, private communication.

Production. — Bismuth is produced now by a few firms in the United States, and the output may increase in the near future.

The imports of metallic bismuth in 1908 amounted to 164,793 pounds, valued at $257,397.

REFERENCES ON BISMUTH

See scattered articles in Mineral Resources of U. S. Geological Survey, and Mineral Industry (N. Y.).

CADMIUM

The chief ore mineral of cadmium is *Greenockite* (CdS), but no deposits of this mineral are known, and the main source of it is cadmiferous zinc ore. Greenockite occurs in the Joplin, Missouri, district as a greenish yellow coating on sphalerite, being a secondary deposit which has been caused by the decomposition of cadmium-bearing blende in the upper part of the ore body, and the precipitation of the sulphide at lower levels. The average percentage in several thousand shipments from the Joplin district was .358 per cent. The table on page 544 gives the analyses of a number of samples of Missouri ore and their cadmium contents.

The calamine ores from Hanover, New Mexico, also contain cadmium in sufficient quantity to give a yellow tint to the zinc oxide made from them.

Since 1907 cadmium has been produced in the United States by one company at Cleveland, Ohio. It is obtained from zinc ores and its production appears to have caused a strong drop in the quantity imported. This is well shown by the fact that the imports for 1907 amounted to 13,808 pounds valued at $10,522, while those for 1908 were 1953 pounds valued at $1633.

Uses of Cadmium. — Cadmium is used chiefly by manufacturers of silver ware, since the addition of only .5 per cent imparts malleability to the alloy and prevents the formation of blisters. While cadmium, like bismuth, reduces the melting point of the alloys into which it enters, it also produces more malleable and ductile ones in most cases, gold, platinum, and copper being an exception. Dental amalgam has 26 per cent cadmium and 74 per cent mercury. The salts of cadmium are used in dentistry, dyeing, glass making, photography, and pyrotechnics.

Analysis of Cadmiferous Zinc Blendes

(W. George Waring, analyst.)

Ore	Zinc	Iron	Lead	Copper	Cadmium
Sphinx mine, Neck City, Mo.	65.77	0.55	0.00	0.077	0.135
Ore from Golconda, Ill.	60.55	1.18	.51	.046	.110
Standard mine, Fortuna, Mo.	61.97	.55	.815	.133	.436
Maude B. mine, Webb City, Mo.	55.70	4.90	Trace	Trace	.227
Big Six mine, Aurora, Mo.	56.75	1.88	None	.004	.018
McKinley mine, Prosperity, Mo.	57.20	1.25	5.29	None	.550
Hudson mine, Pleasant Valley, Mo. . . .	62.05	.61	None	.030	.322
Underwriters' mine, Webb City, Mo. . .	57.95	1.60	1.62	—	.710
Blende from Kentucky fluorspar mines . .	53.50	.77	.76	None	.211
Average of 2270 carloads from Webb City, Mo., 1902 . .	57.08	2.60	.90	.050	.337
Average percentage of cadmium in 10,906 shipments, mostly carload lots . . .	—	—	—	—	.358

REFERENCES ON CADMIUM

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CHROMIC IRON ORE

Ore Minerals. — *Chromite* (FeO, Cr_2O_3) is the chief source of the compounds of the metal chromium which are used in the arts. This ore occurs sometimes in alluvial deposits, but more commonly in basic magnesian rocks, notably serpentine.

A number of other minerals contain chromium, but they are not of commercial importance.

Origin of Chromite. — It has been pointed out by Pratt (4) that chromite occurs most commonly around the border of basic magnesian rocks of igneous origin. This is believed to indicate that the chromium existed in the original molten rock, and that, as this basic magma cooled, the chromite, being one of the earliest minerals to crystallize, separated out along the border of the mass because this portion was the first to cool. As the cooling proceeded, convection currents within the molten mass would bring additional supplies to the border.

Analyses (5). — The following table gives the composition of several of the types of chromic iron ores: —

	France	Coleraine, Can., Concentrated Product	Asia Minor	Styria	Calif.	Russia
Cr_2O_3 . .	37.00	53.64	53.00	53.00	42.20	59.00
SiO_2 . . .	2.53	2.31	2.15	2.50	5.48	2.20
Al_2O_3 . .	13.15	14.02	7.62	8.00	13.60	10.00
MgO . .	12.53	15.75	13.31	11.58	14.88	11.62
FeO . . .	34.79	11.47	24.92	24.92	23.84	18.18
CaO . . .	—	2.81	—	—	—	—

The price of chromic iron ore is based on its percentage of chromic oxide, the standard ore containing 50 per cent. Every unit above this is valued at from 75 cents to $1 per ton; but when the percentage is below 50 per cent, the value decreases at an even greater rate. However, ores carrying only 45 per cent of chromic oxide are easily marketable. Low silica is desirable.

Distribution in the United States. — Chromite mining is an industry of very little importance in the United States, because the deposits, though widespread, are rarely of workable size. The ore was for a time obtained from Chester and Delaware counties, Pennsylvania, and Baltimore County, Maryland, and the exhaustion of these deposits was followed by the opening of others in San Luis Obispo County, California. Subsequently the importation of Turkish and Russian chromite commenced, followed by additional supplies from Canada and Newfoundland. This foreign chrome iron ore, especially the Turkish, can be placed on the American market so cheaply that there has been little development of our own deposits. The importation of chromic iron ore from New Caledonia is also increasing.

The only deposits in California (6) which are at present operated are those on Shot Gun Creek in western Shasta County. The ore, which occurs in serpentine, forms a series of five lenses, containing from 200 to 1500 tons each, and connected by vein-like stringers in a nearly vertical shear zone. The ore analyzes 43.87 Cr_2O_3 and 15.86 FeO.

Deposits of chromite are known to occur in the serpentine of southern Pennsylvania and northern Maryland; also in the peridotites (dunite) of western North Carolina. They are of no commercial importance at the present time. A promising deposit is said to have been discovered in Deer Creek Cañon, Converse County, Wyoming (6).

Uses. — Metallic chromium has no direct use; but raw chromite and chromium salts have a variety of applications. Owing to its great heat-resisting qualities, chromite is employed in the manufacture of refractory bricks. Such bricks are sometimes used for lining basic open-hearth furnaces, and as a hearth lining for water-jacket furnaces in copper smelting. They stand rapid changes of temperature well, and are not attacked by molten metals.

In the presence of carbon, chromium makes steel extremely hard and resistant to shocks; therefore chrome steel is suited to a variety of uses, as in the manufacture of plates, hard-edged tools, etc. An alloy of iron and chromium is used in armor plates, alloys of ferrochromium and ferronickel being added to the molten steel before casting. Most of the chromite mined is used for pigments because of the red, yellow, and green color of its compounds, chromate and bichromate of potash. In these forms the substance is employed in dyeing, calico printing, and the making of pigments useful in painting, printing wall papers, and coloring pottery. Alkaline bichromates are employed for tanning skins, and some chromium salts have a medicinal value.

Production of Chromite. — The amount of chromite produced in the United States is small, and in 1903 California was the only source of supply. The production for several years was as follows: —

PRODUCTION OF CHROMITE IN THE UNITED STATES FROM 1904 TO 1908

YEAR	QUANTITY LONG TONS	VALUE
1904	123	$1,845
1905	22	375
1906	107	1,800
1907	290	5,640
1908	359	7,230

The value of the imports for the last three years was: —

YEAR	CHROMATE AND BICHROMATE OF POTASH	CHROMIC ACID	CHROME ORE	TOTAL
1906	$2,124	$331	$557,594	$560,049
1907	1,307	403	491,925	493,635
1908	15,453	708	345,960	362,121

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MOLYBDENUM

Ores and Occurrences. — *Molybdenite* (MoS_2) and, less commonly, *Wulfenite* ($PbMoO_4$) are the chief sources of this metal.

Molybdenite forms irregular masses or disseminations in crystalline rocks, and many occurrences are known in the West, for example in California, Washington, Montana, Utah, Arizona, New Mexico, and in the East, in Maine. Wulfenite is found in the oxidized zone of lead ores in a number of western states. An ore to be marketable must contain over 45 per cent of molybdenum and be free from copper, the average price of a 50 to 55 per cent ore being about $400 per ton.

Uses. — Its chief use is in the manufacture of chemicals, especially ammonium molybdate, and for coloring porcelain green. A nickel-molybdenum alloy is also made. The use of molybdenum for hardening steel is increasing, it being used chiefly for tool steel.

Production of Molybdenum. — The production of molybdenum is small. No sales were reported for either 1907 or 1908, but a small amount was mined in Washington in the former year.

REFERENCES ON MOLYBDENUM

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NICKEL AND COBALT

Ore Minerals. — These two metals can best be treated together, for nearly all the ores containing the one are apt to carry some of the other, and furthermore, in smelting, the two metals go into the same matte, and are separated later in the refining process.

The ore minerals of nickel and cobalt, of recognized occurrence in the United States and Canada, together with their composition and the percentage of nickel or cobalt they contain, are: —

Ore	Composition	Ni	Co
Pyrrhotite (nickeliferous)	$Fe_{11}S_{12}$	0–6	—
Millerite	NiS	64.6	—
Pentlandite	$(FeNi)S$	22	—
Genthite	$2\,NiO_2, 2\,MgO, 3\,SiO_2, 6\,H_2O$	22.46	—
Niccolite	$NiAS$	43.9	—
Linnæite	$(CoNi)_3S_4$	30.53	21.34
Chloanthite	$NiAs_2$	28.1	—
Smaltite	$CoAs_2$	—	28.1
Cobaltite	$CoS_2, CoAs_2$	—	35.4
Erythrite (Cobalt bloom)	$Co_3As_2O_8 + 8\,H_2O$	—	37.47
Annabergite (Nickel bloom)	$Ni_3As_2O_8 + 8\,H_2O$	—	—

Of the above some occur only in small amounts as Millerite, Pentlandite, Genthite, and Chloanthite.

Others not of importance on this continent are Garnierite, Pimelite, and Schuchardite, hydrated nickel magnesium silicates of variable composition, but containing up to 25 per cent NiO; also Gersdorffite (NiAsS, 35.4 per cent Ni).

The nickeliferous pyrrhotite is the most widely distributed of the nickel ore minerals and may carry small amounts of cobalt. It is also called magnetic pyrites. The percentage of nickel ranges from a trace to 6 per cent, but an increase above this brings it into pentlandite. The millerite is sometimes found associated with pyrrhotite ores.

Distribution. — Very little direct mining for nickel and cobalt is done in the United States, but at Mine la Motte, Missouri, considerable quantities have been obtained annually as a by-product in lead mining.

Missouri. — The ore at Frederickstown, Missouri, is a mixture of chalcopyrite, galena, linnæite, and pyrite. The lead is removed as far as possible in concentration, and the iron by roasting and magnetic separation. The resulting concentrate is smelted (13).

Eastern Occurrences of Nickel. — The Gap Nickel Mine, Lancaster County, Pennsylvania, is the most important eastern occurrence. It was actively worked from 1863 to 1880, being during that period the only nickel ore mined on this continent. In 1902 the mine was again operated for a short time. The ore is pyrrhotite associated with amphibolite, an altered intrusive, the whole inclosed by mica-schist. The pyrrhotite is believed to have originated by magmatic segregation (9).

Nickel has been reported from a number of localities in the Piedmont region of Virginia (14), especially in association with the pyrrhotite bodies of the Floyd-Carroll-Grayson counties plateau in southwest Virginia, as well as at several other points. No steady production has been made, but the locality in northern Floyd County is encouraging. There the ore which occurs in a mica gabbro is said to average 1.75 per cent nickel, and under 1 per cent of copper. Cobalt is usually very low. Nickel minerals have also been found in the basic magnesian rocks of North Carolina.

Western Occurrences. — Deposits of nickel and cobalt ores are known in Idaho and Oregon, but they have not yet assumed importance.

The only production in 1907 was near Prairie City, Grant County, Oregon, but the deposits which have attracted the most attention from time to time are those of Piney or Nickel Mountain near Riddles (8), Douglas County, in the same state.

The ore, which is genthite in a quartz gangue, occurs as flat-lying deposits on the surface of post-Cretaceous pre-Eocene peridotite, or as veinlets in the peridotite and serpentine. The former deposits occur as brecciated and conglomeratic masses, and consist of silica, nickel silicate, ferric oxide, and serpentine with very subordinate chromite. Prolonged weathering in some cases has removed the nickel.

It is thought that the genthite represents a decomposition product of the peridotite, for nickel is found in the fresh rock. The hydrated nickel-magnesian silicates and silica formed by weathering were subsequently in part dissolved and carried down into crevices of the underlying peridotite. Such a theory limits the depth. If formed by ascending hot waters, as some believe, a greater depth would be assured.

Canadian Occurrences. — Canada is the most important source of the nickel and cobalt ores in North America, and much of the mine production is shipped to the United States for treatment and consumption. It is therefore of interest to refer to the two important producing localities, viz. Sudbury and Cobalt, both in the province of Ontario.

Sudbury, Ontario (1, 2, 3, 4, 5). — This district is the main source of supply for the nickel used on this continent.

The ore bodies are found at or near the margin of a huge laccolithic sheet of eruptive rock about 1¼ miles thick, 36 miles long, and 17 miles wide, the geological section involving a series of pre-Cambrian rocks, as shown below.

Pleistocene		Sand and clay
Keweenawan		Latest granite dikes Olivine diabase dikes Granite Sudbury nickel-bearing eruptive
Animikie		Chelmsford sandstone Onwatin slate Onaping tuff Trout Lake conglomerate
Archæan	Laurentian	Granitoid gneiss
	Huronian	Acid and basic Huronian eruptives Ramsay Lake graywacke conglomerate Copper Cliff arkose McKim graywacke

Reference to the section (Fig. 235) will show that the nickel-bearing laccolith rests on ancient crystallines and is covered by metamorphosed Animikie sediments; that, moreover, the underlying

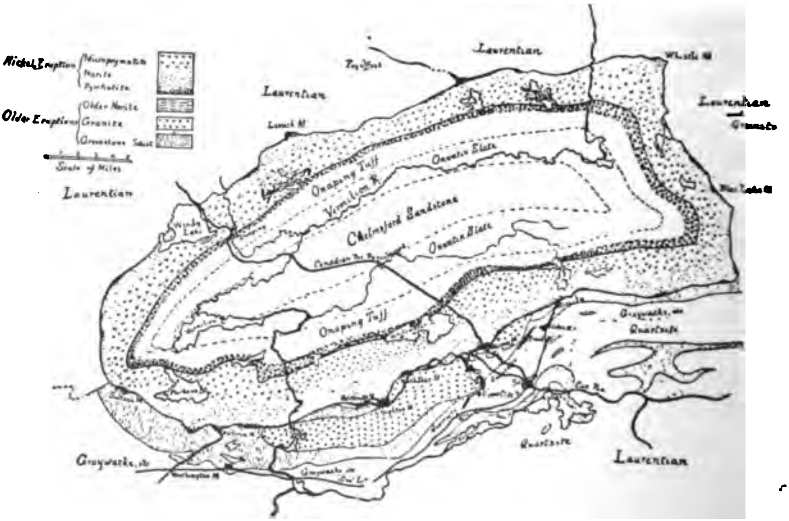

FIG. 234. — Geologic map of Sudbury, Ont., nickel district. (*After Coleman.*)

and overlying formations are bent into a great canoe-shaped trough or basin.

As shown by the section (Fig. 235), the laccolith rests on ancient crystallines and is covered by metamorphosed Animikie sediments. The intrusive where fresh is a norite on its outer border or lower part, and passes by insensible gradation into a granite on its inner edge (Fig. 235).

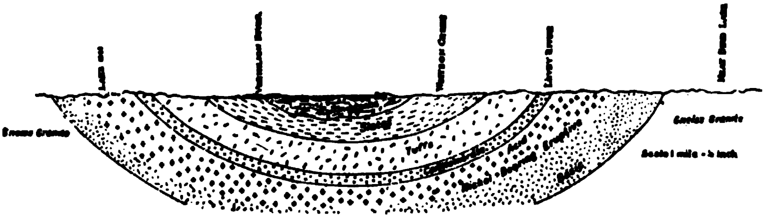

FIG. 235. — Geologic section of Sudbury, Ont., nickel district. (*After Coleman.*)

Coleman believes that following the eruption of the nickel magma there was a long-continued process of segregation, resulting in an accumulation of the more basic elements of the molten mass in its lower part, and the more acid elements in its upper portion, the sulphides sinking into the depressions of the Archæan substratum. The collapse of the underlying Archæan, due to the upflow of the magma from underneath, is supposed to have caused a sinking of the overlying rocks, and formation of the trough. The ore bodies occur only in the norite, around its margin, or in some of the dike-like offsets.

The ores, which are of remarkably uniform character, consist mainly of pyrrhotite, chalcopyrite, and pentlandite, and though the last is important, it is rarely visible to the naked eye. Variations in the proportions of these three may, however, occur. Thus, in the Copper Cliff mine, the percentages were 4.65 Cu to 4.46 Ni one year, while in another they were 7.81 Cu to 2.37 Ni.

The ore bodies are sometimes found on the margin of the eruptive, and have a foot wall of the older rocks, but an ill-defined hanging wall. These form irregular sheets dipping towards the synclinal axis. Others, of irregular shape, are found in the dike-like projections of the basic edge.

Several theories have been advanced to account for the origin of these ore bodies. Coleman believes the ore is of magmatic origin because (1) it is everywhere associated with norite, and grades into it. (2) The adjoining rocks are never spotted with ore, and separated bodies of ore are never inclosed in them, but veinlets of ore may penetrate them. (3) There is little evidence of hydrothermal or pneumatolytic action, such as one might expect if the deposits were other than magmatic segregations. (4) The largest bodies are in the offsets, which represent the lowest portions of the laccolith, and into which the ore would naturally settle. Barlow, who has also made a somewhat careful study of this district, concurs with Coleman regarding the origin of the ore by magmatic segregation. It is, of course, not improbable that the ore bodies have been rearranged somewhat later by circulating water.

At some variance with these views are those expressed by Dickson (6). His theory is that the ore occurs as a cement for brecciated rock fragments and along shearing planes which are of pre-mineral age, the ore minerals having been deposited by solutions and by a process of replacement. This view seems to be confirmed by the examination of the minerals of this district by metallographic methods, which show the following order of succession: (1) Magnetite, (2) Silicate, (3) Pyrrhotite, (4) Pentlandite, (5) Chalcopyrite.

According to Coleman, the percentage of sulphides in the ores varies from 50 to 80, while the nickel contents ranges from 1.5 to 5 per cent. The cobalt is present in amounts varying from $\frac{1}{40}$ to $\frac{1}{188}$ of the nickel present.

An analysis of a high-grade matte gave: NiCo, 48.82; Cu, 25.92; Fe, 2.94; S, 22.50; Au, .02 oz.; Ag, 3.14 oz.; Pt, .13; Ind., .02; Os, .02; Rh and Pal., tr.

Cobalt, Ontario (10). — The silver-cobalt-nickel veins found at this locality present one of the most remarkable series of ore deposits found in recent years, and have their analogue only in certain foreign occurrences. The district lies near the boundary of the provinces of Ontario and Quebec, and west of the northern end of Lake Temiskaming.

The ores occur in mostly well-defined veins, which range from less than an inch to as much as a foot or more in thickness, and occupy narrow, almost vertical fissures or joints, cutting through a series of slightly inclined metamorphosed fragmental rocks of Lower Huronian Age. Some are also found in the diabase and Keewatin, although these last two are never so productive.

The geological section at this locality is as follows ;—

1. Glacial drift.
2. Niagara limestone.
3. Post-middle Huronian diabase, forming sheets and sills.

4. **Middle Huronian arkoses, conglomerates, and quartzites.**
5. **Lower Huronian conglomerate, graywacke slate, and conglomerate, laid down after an erosion interval, on the uneven Keewatin floor, and not less than 500 feet in thickness.**
6. **Keewatin igneous complex of diabase and related rocks, together with granite porphyry, etc. The formation has been folded and afterwards intruded by granite.**

The important ores are native silver, smaltite, and cobaltite, but associated with them in varying quantities are niccolite, chloanthite, millerite, argentite, dycrasite, pyrargyrite, arsenopyrite, etc. The oxidized zone, which is usually but a few feet in depth, shows native silver, erythrite (cobalt bloom), and annabergite (nickel bloom). Calcite is the chief gangue mineral, quartz being much less common.

W. G. Miller (10), who has given more careful study to this region than any one else, believes that the ore was deposited by highly heated impure waters circulating through cracks and fissures following the post-middle Huronian diabase eurption. The metals may have been brought up by these waters from a great depth, or they may have been leached out of the now folded and disturbed greenstones and other Keewatin rocks. He inclines to the theory, however, that the diabase magma was the source of both the cobalt-nickel minerals and the silver.

The cobalt arsenides were probably the first minerals deposited, and this was followed by a slight disturbance of the veins, resulting in the formation of cracks and openings in which the silver and later minerals were deposited. Veins which escaped this latter disturbance contained no silver. Many of the veins of this district are fabulously rich, but all are not so. As an example of the former, an open cut on the Trethewey vein, 80 feet long and 25 feet deep, yielded $200,000 of ore from an 8-inch vein. A shipment of 80 tons of this ore gave approximately: As, 38 per cent; Co, 12 per cent; Ni, 3.5 per cent; and 190,000 ounces silver. Pay was received only for the cobalt and silver.

The veins at Cobalt are unique among North American ones, but resemble those of Annaberg, Joachimsthal, and other localities.

The discovery of these deposits was made in building the Temiskaming and Northern Railroad, and their development has made Ontario one of the leading silver producers of the world. Moreover, it practically controls the world's supply of cobalt, and the arsenic shipped from the Cobalt camp equals about one half of the world's production, but much of it is not saved.

Milling plants have recently been installed for concentrating the lower-grade ores. The ores are treated in part in the United States, but there are now plants erected for this purpose at Copper Cliff, Deloro, and Thorold, Ontario.

Uses of Nickel. — The most important and increasing use of nickel is for the manufacture of nickel and nickel-chromium steel. This, on account of its great hardness, strength, and elasticity, is used for making armor plate, gun shields, turrets, ammunition hoists, etc. Krupp steel, which may be taken as a type, has approximately 3.5 per cent nickel, 1.5 per cent chromium, and .25 per cent carbon. Owing to its abrasive resistance, nickel steel is now much used for rails. Other important uses are for large forgings, marine engines, wire cables, and electrical apparatus. A steel with 25 to 30 per cent nickel shows high resistance to corrosion by salt, fresh or acid waters, or by superheated steam. German silver is an alloy of zinc, copper, and nickel. Monel metal is an alloy containing 68 per cent nickel, 1.5 per cent iron, and 30.5 per cent copper.

Uses of Cobalt. — Cobalt steel, while having a high elastic limit and breaking strength, cannot compete with nickel steel on account of its high cost, and the main use for cobalt is as a pigment, it being used to color glass and pottery.

Production. — The production of nickel from domestic ores and cobalt oxide in the United States from 1892 to 1901 was:—

PRODUCTION OF NICKEL AND COBALT FROM DOMESTIC ORES

YEAR	NICKEL		COBALT OXIDE
	Quantity Pounds	Value	Quantity Pounds
1892	92,252	$50,739	7,869
1895	10,302	3,091	14,458
1900	9,715	3,886	6,471
1901	6,700	3,551	13,360
1902	5,748	2,701	3,730
1903	114,200	45,900	120,000 [2]
1904	24,000	11,400 [1]	22,000 [2]
1908	500,000	250,000 [3]	——

[1] This is the last year for which separate production is given.

[2] Including cobalt oxide in ore and matte.

[3] Mineral Industry, XVII.

The imports of cobalt oxide, etc., in 1908 were 219,098 pounds, valued at $17,077, while the total value of the nickel ore matte, etc., imported in the same year was $2,497,895. The exports of nickel oxide and matte in 1901 were $3,297,988.

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PLATINUM GROUP OF METALS

Platinum. — The ores mineral of platinum are *Native platinum* (100 per cent Pt) and *Sperrylite*, $PtAS_2$ (56.5 per cent Pt). The former is commonly found in placer deposits, but it has also been noted in basic igneous rocks rich in olivine, such as peridotite, or in serpentine derived from it. The sperrylite never occurs in large quantities, but has been found in association with nickel and copper ores. Iridosmine and osmiridium are also known to carry platinum.

The nuggets found in placers are commonly regarded as being pure native platinum, but this, according to Kemp (4), is only true in part, most of those assayed yielding between 70 and 85 per cent, and the richest recorded being 86.5 per cent. The balance is made up largely of iron, the highest percentage of this noted being 19.5 per cent in a Ural specimen. Iridium, rhodium, and palladium are always present. Until the platinum falls below 60 per cent the iridium rarely reaches 5 per cent, rhodium 4 per cent, while palladium is less than 2 per cent. Other elements that have been detected in the nuggets are osmium, ruthenium, copper, and even gold, while chromite is a common associated mineral (4).

Distribution in the United States. — The domestic supply of platinum, never large, is obtained from gold-placer deposits in Oregon and California, and while its occurrence has been reported in many other gold placers of the Northwest and Alaska, still none of them have proven sufficiently rich to work. Most of the California production comes from the dredges at Oroville, in Butte

County. The platinum is usually panned from the black sand, but a small quantity is entangled with the amalgamated gold and recovered in refining at the mint. Iridosmine and a natural alloy of iron and nickel called josephinite are found associated with the gold.

In addition to the above sources, platinum is also found in the copper ores of the Rambler mine, Wyoming, and has been saved from the slimes obtained in treating the copper ore and matte at this locality. The covellite in the ore is said to assay .06 to 1.4 ounces per ton of platinum.

Uses. — Platinum was first used as an adulterant of gold, and in Russia it was used for coinage from 1828 to 1845. At the present time it is employed for crucibles and other chemical apparatus which are to be subjected to high temperatures or strong acids. It is also of value in dentistry, for electric lamps and electric apparatus, for jewelry, and in photography. The price of it has risen steadily in recent years, so that it is as valuable as gold.

Production. — The production in the United States from 1880 to 1908 was as follows: —

PRODUCTION OF PLATINUM IN THE UNITED STATES

YEAR	QUANTITY OUNCES	VALUE	YEAR	QUANTITY OUNCES	VALUE
1880	100	$400	1903	110	$2,080
1885	250	187	1904	200	4,160
1890	600	2,500	1905	318	5,320
1895	150	900	1906	1439	45,189
1900	400	$2,500	1907	357	10,589
1901	1,408	27,526	1908	750	14,250
1902	94	1,874			

Since the close of 1899 platinum has risen steadily in price, reaching a maximum of $38 per ounce in 1907, but dropped to $29 in 1909.

The imports of platinum, both crude and manufactured, amounted to $2,684,642 in 1907, and $1,229,873 in 1908. The domestic production is entirely inadequate to supply the demand, and the greater portion of the supply of the United States, and in fact the world, is obtained from the platinum placers of the Urals (5). The Russian production for 1908 was estimated at 138,000 troy ounces.

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Palladium. — This metal is found associated with platinum and also native and alloyed with gold (Brazil). It is of silver-white color, ductile and malleable, and is unaffected by the air. Its great rarity and consequent high value has restricted its use, but a small amount is used for some mathematical and surgical instruments, for compensating balance wheels and hairsprings for watches, and for finely graduated scales.

In the United States it has been reported from the platinum deposits of the Pacific coast and from the Rambler mine in Wyoming.

Osmium. — This, the heaviest and most infusible metal known, occurs alloyed with platinum and also with iridium in iridosmine. In the United States small quantities have been found in the platinum placers of California.

Iridosmine is employed for pointing pens and fine tools, while osmic acid is used for staining anatomical preparations in microscopic work.

Iridium. — Iridium is found chiefly in Russia and California, alloyed with platinum or osmium. It is a lustrous, steel-like metal of great hardness, and is, next to osmium, the most refractory metal known.

An alloy of iridium and platinum has been used for standard weights and measures, and iridium is also used in photography.

SELENIUM

This rare and little-known element is not known to occur in deposits by itself, but is found in some gold and silver ores at least.

Thus Spurr has called attention to its presence in the gold ores of Tonopah, Nevada, where it is found, at least in part as a silver selenide. It is obtained in several instances in the refining of gold or copper ores, being sometimes separated from the flue dust.

The domestic consumption of selenium does not exceed a few thousand pounds per year, and the price is said to range from $5 to $16 per pound.

Uses. — Selenium is used as a red colorant of glass, while selenite of soda gives a bright red color to enamels used for covering steel. Owing to its low electrical conductivity in the light, and higher conductivity in the dark, selenium wire is used in automatically lighting and extinguishing gas buoys.

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TANTALUM

This element has attracted some attention because of its use in electric lamps.

Tantalite ($FeTa_2O_6$) and columbite [$(Fe, Mn)Nb_2O_2$] are the only minerals found in the United States from which tantalum could be produced. They occur in pegmatite veins, and are said to be found in some abundance in those of the Black Hills of South Dakota. Other occurrences are near Canyon City, Colorado; near Spruce Pine, North Carolina; near Amelia, Virginia, etc.

The tantalum market is now said to be supplied mainly by the rich mangano-tantalates from western Australia (2). Scandinavia has also supplied some (4).

REFERENCES ON TANTALUM

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TELLURIUM

This element has no commercial value except as a chemical curiosity. The somewhat widely distributed telluride of gold and silver ores form a comparatively common source of it, but owing to the lack of demand, no attempt is made to save the tellurium. Cripple Creek, Colorado, is the best-known occurrence in the United States.

TIN

Ore Minerals. — *Cassiterite* (SnO_2), with 78.6 per cent metallic tin, is the principal ore mineral of this metal, but owing to the presence of impurities it rarely shows this composition.

Its hardness (6–7), imperfect cleavage, non-magnetic character, high specific gravity (6.8–7.1), and brittleness help to distinguish it from other minerals that are liable to occur with it. Ilmenite and magnetite have sometimes been mistaken for it.

Stream tin is the name applied to cassiterite found in placers. *Wood tin* is a variety of cassiterite having a fibrous structure. *Stannite,* or tin pyrites, a complex sulphide of copper, iron, and tin, rarely serves as an ore mineral.

Mode of Occurrence. — Cassiterite exhibits three common modes of occurrence, viz. (1) in veins, (2) in placers, and (3) in dikes. The placers are the most important source.

Cassiterite Veins.—These are usually found in granite, or close proximity to it, and are filled with a mixture of quartz and feldspar, carrying cassiterite and a number of other minerals, some of them rare. The veins have probably been formed by magmatic emanations which contained fluorine, and also attacked the walls, inducing strong metamorphic action. As a result of this the feldspar and mica are altered to lepidolite or zinnwaldite, and replaced by cassiterite. The resulting quartz-mica rock or *greisen* grades outward into the normal granite.

The actual veins may be narrow, but the greisen zone quite wide, and less resistant to the weather than the vein matter.

Vogt, Beaumont, Daubrée, and others believe that the tin veins were formed immediately after or even during granitic eruptions, and that the mineral solutions originated by the action of hydrofluoric or hydrochloric acid on the magma, still entirely or partly in igneous fusion. These extracted fluorides of silicon, tin, boron, and lithium as well as phosphoric acid. The type of alteration of these pneumatolytic emanations varies somewhat, schist being altered somewhat differently from granite.

The most characteristic gangue minerals of tin veins besides feldspar and quartz are: lepidolite, zinnwaldite, topaz, tourmaline, apatite, wolframite, molybdenite, scheelite, fluorite, and arsenopyrite.

Cassiterite Dikes (7). — Cassiterite sometimes occurs as a primary constituent of igneous rocks, usually pegmatite. These dikes may also carry lithium and phosphorus minerals. They exhibit sharp walls, and there is no replacement of the wall rocks by cassiterite. They resemble pneumatolytic veins in being the last products of eruption of granitic magma, and may in some instances possibly grade into them.

Placer Deposits. — These are formed in the usual way by the products of disintegration from tin lodes being washed down into streams.

Other Types. — Tin appears to be formed in some cases by precipitation at normal pressure from thermal waters, for a stanniferous siliceous sinter has been deposited by a hot spring in Malacca. It contains SiO_2, 91.8; SnO_2, .5; Fe_2O_3, .2; and H_2O, 7.5 (quoted by Lindgren).

Distribution of Tin Ores in the United States. — Tin has been found at many localities in both the eastern and western United States as well as in Alaska, but most of the deposits are of no commercial value.

North Carolina and South Carolina (7, 8). — In these two states there is a belt of tin ore which once rose to prominence and then died out. It extends from near Gaffney, Cherokee County, South Carolina, across parts of Cleveland and Gaston Counties, North Carolina, to near Lincolnton, being in all 35 miles long. The cassiterite is irregularly distributed in pegmatite dikes in schists, the latter being metamorphosed sediments interstratified with slates, marbles, and quartzites. Gabbro, diabase, and granite intrusions are also present.

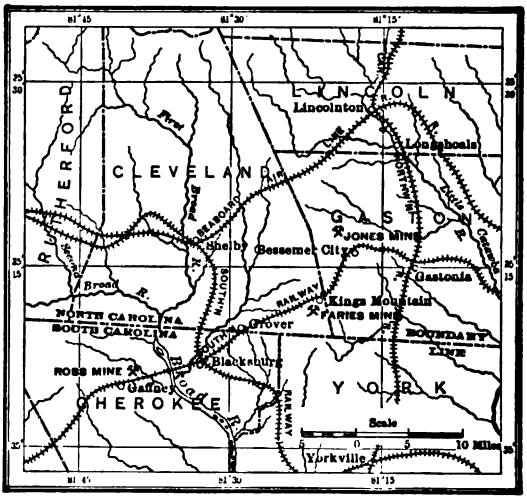

FIG. 236. — Sketch map showing location of Carolina tin belt. (*After Graton, U. S. Geol. Surv., Bull.* 260.)

South Dakota and Wyoming (10). — The most widely known occurrence in the United States is in the Black Hills. Tin was discovered in the Harney Peak district and later in Nigger Hill. The deposits occur as impregnations in pegmatites, in quartz veins, and in placers. They have never amounted to much.

Alaska (5, 11). — Tin is found in the York region of the Seward Peninsula, and occurs chiefly in placers and lodes. The lode deposits show the following types: (1) quartz veins cutting phyllites or metamorphic slates; (2) disseminations in more or less altered granite rocks; (3) in quartz porphyry dikes cutting limestone, and accompanied by fluorite, zinnwaldite, etc.

In 1908 the only domestic production came from the Alaskan placers.

Uses of Tin. — Tin is used chiefly for the manufacture of bronze and tin plate, and to a smaller extent in plumbing as well as less important purposes. Britannia metal is composed of from 82 to 90 parts of tin alloyed with antimony, copper, and sometimes zinc.

Production of Tin. — The amount of tin produced in the United States including Alaska is entirely too small to supply the demand, and the main source of supply for this country, and indeed for the world, is the Malay peninsula, while other regions of commercial importance are Australia and Bolivia. The available figures are given below: —

PRODUCTION OF TIN AND TIN ORE IN VARIOUS COUNTRIES IN 1908, IN SHORT TONS

	QUANTITY	VALUE
South Africa, exports	2,361	$555,467
Federated Malay States, exports	56,935	—
Tasmania, ore	5,063	2,051,619
Australia:		
New South Wales { ore	942	385,208
New South Wales { tin ingots	1,068	614,600
Victoria, ore	89	29,540
Western Australia, ore and ingots	1,224	405,355
Northern territory, exports, ore	501	175,145
Queensland, ore	5,404	1,665,273
Italy (Province of Pisa), ore	272	3,814
Singkep, pig tin	499	262,995
Bolivia, ore	32,932	10,756,800
Burma, ore	106	53,604

TIN IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES, 1904–1908, IN SHORT TONS

YEAR	QUANTITY	VALUE
1904	41,472	$22,356,895
1905	44,188	26,316,023
1906	50,477	37,447,315
1907	41,257	32,074,263
1908	41,267	23,932,560

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TITANIUM

Ores. — Among the minerals carrying titanium the most abundant is *Ilmenite* (FeO, TiO_2), which occurs in many deposits of magnetite. *Rutile* (TiO_2, 60 per cent Ti when pure), though less abundant, is not uncommon. Titanium is also found in a number of other minerals, many of which are rare.

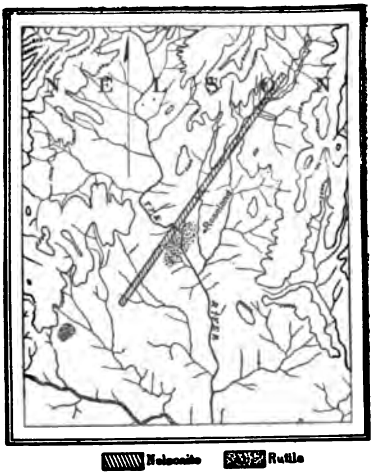

FIG. 237. — Map showing location and relations of rutile deposits in Nelson County, Va. (*After Watson, Min. Res. Va.*, 1907.)

Occurrence.—For many years Norway has been the chief producer of this metal; but in 1900 large deposits of rutile were discovered in Virginia.

Prior to the opening of these the domestic demand which has been small was supplied by deposits in Chester County, Pa.

The Virginia (4) rutile deposits lie about 7 miles north of west from Arrington (Fig. 237). The rutile occurs in various-sized grains and crystals of remarkable purity, disseminated through the feldspar, blue quartz, and hornblende, of a massive, pegmatite-like rock of probable igneous origin, and is remarkably free from other metallic minerals. The rutile, which varies from scant disseminations up to 30 per cent, but averaging 10 per cent, is believed to be a primary constituent of the rock in which it occurs, for the reason that it is interlocked with the other minerals, is not developed along their cleavage planes, and fractures cross all minerals alike. The country rock is a gneiss, which carries occasional rutile grains, and is cut by numerous acid pegmatite dikes, as well as occasional ones of diabase and gabbro.

A second type of occurrence, known as nelsonite rutile, is found in an evenly granular rock, of dike-like character, and composed normally of ilmenite and apatite. In some places the ilmenite is almost completely replaced by rutile.

Both types are being mined.

Uses. — Titanium is used for producing yellow underglaze colors on pottery, and also in the manufacture of artificial teeth, to give them an ivory tint. Another use is in the alloy ferro-titanium. Its commercial values as a steel-hardening metal are not yet thoroughly proven, but from .5 to 3 per cent titanium appear to materially increase the transverse and tensile strength of steel. By the use of the electric furnace, ferro-titanium can be produced directly from the ores, which would open a use for our American titaniferous magnetites.

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TUNGSTEN

Ore Minerals. — Four minerals may serve as sources of the tungsten of commerce, viz.: *Hübnerite* ($MnWO_4$, 76.6 per cent WO_3); *Wolframite* ($(FeMn)WO_4$, 76.4 per cent WO_3); *Scheelite* ($CaWO_4$, 80.6 per cent WO_3); *Ferberite* ($FeWO_4$, 76.3 per cent WO_3).

Of these the wolframite is the most abundant, while scheelite and ferberite are somewhat rare. The tungsten ores are usually found in veins cutting igneous or metamorphic rocks, but they may also occur as replacements, in limestone, etc. The tungsten mineral forms the most prominent mineral in a deposit, or occurs as a subordinate one in veins carrying tin, gold, or silver.

Among the minerals that may be found accompanying tungsten are galena, pyrite, siderite, quartz, chalcopyrite, pyrrhotite, fluorite, tetrahedrite, sphalerite, barite, etc.

In most cases the ore appears to have been deposited by thermal solutions, but its occurrence in some tin veins suggests that it may be of pneumatolytic origin.

Distribution in the United States. — Tungsten minerals are known to occur at a number of localities in the United States, and yet but very few of these are of commercial importance. Nevertheless the quantity available exceeds the demand. Colorado, Montana, and Arizona were the only producers in 1908.

A few of the occurrences are referred to below, partly to give some idea of the mode of occurrence.

Colorado (7).—The most important tungsten deposits of Colorado are found in southeastern Boulder County. The country rock, which is pre-Cambrian granite and gneiss, has been subjected to fissuring accompanied by crushing and brecciation, and in the open spaces thus formed the ore mineral ferberite has been deposited. The metalliferous solutions also carried much silica, and the following important periods of mineralization have been distinguished, each separated by secondary movement and brecciation along the veins: 1. silicification and partial cementation of breccia with slight deposition of tungsten; 2. deposition of tungsten; 3. precipitation of silica followed by second important deposition of tungsten. There is also a strong suggestion of solution and secondary enrichment. The friable character of the ferberite and the highly siliceous nature of some of the ores cause some difficulty in concentration.

These deposits form the most important domestic source of tungsten at the present time.

Arizona (2, 5, 12, 17). — Hübnerite is found irregularly distributed in vertical quartz veins cutting granites and gneissic rocks, near Dragoon, Cochise County.

California (1). — Scheelite-bearing veins occur in the Randsburg district in a grano-diorite or schist. The veins occupy a shear zone, and the gangue is mainly quartz.

Nevada (20). — Veins of hübnerite are found in a granite porphyry in the Tungsten mining district southeast of Ely. The gangue is quartz with a little fluorite, pyrite, and scheelite.

South Dakota (10). — Wolframite is found near Lead City as flat, horizontal, but irregular masses, associated with the oxidized, refractory siliceous gold ores. These ores are replacements of a dolomite deposited by uprising thermal solutions.

Uses of Tungsten. — Most of the tungsten produced is used in the manufacture of tool steel, and the industry therefore depends to a large extent on the condition of the steel industry. Tungsten forms a number of alloys with other metals such as iron, aluminum, nickel, copper, titanium, tin, etc. It is also employed to a considerable extent for incandescent lamp filaments. Ferro-tungsten is used in the manufacture of tungsten steel, and the fluorescent properties of tungstate of lime make it useful in the Röntgen ray apparatus. Tungsten is also employed for coloring glass, sodium tungstate is used in fireproofing curtains and draperies, while other tungsten salts are used for weighting silks.

Production. — The production, never large, fell off considerably in 1908, due to the business depression of the previous year.

PRODUCTION OF CONCENTRATED TUNGSTEN ORES IN THE UNITED STATES, 1900–1908, IN SHORT TONS

YEAR	QUANTITY	VALUE	YEAR	QUANTITY	VALUE
1900	46	$11,040	1905	803	$268,676
1901	179	27,720	1906	928	348,867
1902	184	34,040	1907	1,640	890,048
1903	292	43,639	1908	671	229,955
1904	740	184,000			

WORLD'S PRODUCTION OF TUNGSTEN IN 1907, ESTIMATED IN SHORT TONS OF CONCENTRATES CONTAINING 60 PER CENT OF TUNGSTEN TRIOXIDE

COUNTRY	AMOUNT	COUNTRY	AMOUNT
South Africa	211	France	67
Malay States	89	German Empire	68
Siam	10	Italy	18
New South Wales	451	Portugal	702
Northern Territory	177	Spain	303
Queensland	703	New Zealand	153
Tasmania	46	United States	1640
West Australia	1	Argentina	507
East Indies	5	Bolivia	500
Austria	50		
England	361		6062

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URANIUM

Two minerals serve as commercial sources of uranium in the United States. These are *Carnotite* and *Pitchblende.*

The most important domestic occurrence of pitchblende is in Gilpin County, Colorado, where it occurs in very thin seams in a granite gneiss. Carnotite occurs as impregnations in sandstone in southwestern Colorado and is referred to under Vanadium.

Uses. — Uranium is of comparatively little practical value. Uranium minerals are radio-active, and the oxide is used to some extent as a coloring agent in pottery glazes and iridescent glass. Certain salts have a limited use in chemistry and medicine.

VANADIUM

There are a number of minerals containing vanadium, but only two are of commercial importance in the United States, viz. *Carnotite* (K_2O, 2 U_2O_3, V_2O_5, 3 H_2O) and *Roscoelite* [H_8K (MgFe) $(AlV)_4$ $(SiO_3)_{12}$].

The chief source of these two minerals has been a somewhat extensive area in western Colorado and adjoining portions of Utah. Near Placerville, Colorado, the Vanadium minerals occur in the La Plata (Jurassic) sandstone, and the common ore is the bright yellow carnotite associated with roscoelite. The mode of occurrence is similar in the surrounding regions.

Uses. — Claims are made for vanadium as a toughener of steel, but there seems to be comparatively little demand for it for this purpose. Metavanadic acid has been used as a substitute for bronze paint, and vanadium chloride is used as a mordant in printing fabrics, and the trioxide as a mordant in dyeing.

During 1908 the United States drew its supply of ore mostly from Peru, where there are large deposits of a sulphide of vanadium known as *Patronite*.

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